A STUDY OF SOME VARIABLES IN AN EXTRUDED PARTICLE BOARD PROCESS

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

Frederick G. Snook

1958

THESIS

ABSTRACT

Snook, Frederick G., A Study of Some Variables in an Extruded Particle Board Process, A bound thesis, 75 pages, 12 tables, 13 figures.

Submitted to the Department of Forest Products, Michigan State University, 1958.

Extruded wood particle board is a relatively new product. This study pertained to a vertical extrusion process for producing particle board, the analysis of some major factors that determine board properties, and the use of results to suggest a possible control method.

The effect of particle production machinery on particle size was studied. Evaluation of particle samples, taken at different locations, indicated that the factors of machine location and operation could combine to produce a high percentage of fine chips among particles used in the product.

Strength values of vertically extruded boards, composed of particles with a high percentage of fine chips and of particles having a low percentage of fine chips, were compared. It was found that, at a given resin content, fine particles have a significant negative effect on modulus of elasticity and rupture values. Small chips also affect the

cohesion of particles perpendicular to the plane of extruded board in a negative manner.

Board thickness and density were measured and the variation determined for a number of raw material combinations. Due to insufficient data, no bases for differences between boards could be established. A highly significant positive correlation was found between thickness and density. The data indicated that variation, from edge to edge, within each board is related to press construction and operation.

Results indicated that a system for controlling particle size and board thickness would assist in improving and maintaining product quality. Simple control charts were derived that could be used to help evaluate trends in particle size and board thickness and also to locate causes for abnormal variation.

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by

Frederick G. Snook

A THESIS

Submitted to the College of Agriculture
Michigan State University of Agriculture and
Applied Science in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE

Department of Forest Products

1958

1-16-59

ACKNOWLEDGMENTS

The author wishes to extend his sincere appreciation to Dr. Aubrey E. Wylie and Dr. Otto Suchsland for their assistance and guidance throughout the entire course of his graduate program.

Acknowledgment is also extended to the Michigan State University Agricultural Experiment Station and the Forest Products Department at Michigan State University both of which provided funds to make this study possible.

Finally the author is indebted to Hart Wood Products Manufacturing Company for their wonderful cooperation and to his wife who acted as typist and moral support during the preparation of the thesis.

TABLE OF CONTENTS

TABLE OF CONTENTS--Continued

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

Preliminary Information

Wood particle board.--During recent years, wood particle board has attained increasing popularity as panelling and core stock material. Estimates of particle board production in the United States during 1956 ranged from 100,000,000 to 250,000,000 square feet, three-fourth inch basis. Estimated 1956 demands of the furniture industry alone were 575,000,000 square feet, three-fourth inch basis(1).

This newly developed product may be defined as a composition board, consisting of many resin-coated wood particles[1] that have been aggregated and cured in a desired form by pressure and heat. Construction may be homogeneous or stratified.

Processes.--The description immediately causes those familiar with pressing operations to think of the board[2] being flat pressed, using a process similar to that used for fabricating plywood. This is the most

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[1]Particles can be small wood pieces in any form, size or shape. This extrusion process utilizes small splinter-like pieces.

[2]The word "board" is used throughout the thesis referring at all times to wood particle board.

common method of manufacture. Recently, however, processes[3] have been developed that produce particle board by extrusion.

Extrusion implies that the product is manufactured by forcing raw material through a die or forming machine. It has found utility and economic feasibility as a production method. In the United States there are at least eighteen plants equipped to manufacture extruded wood particle board.

Review of literature.--An investigation of past work revealed that, although a considerable amount of research has been performed on wood particle board, the major emphasis was placed on that produced by flat pressing. No objective study of extrusion process variables had been undertaken. It was felt some study of product and process characteristics, for an extrusion method, was warranted.

Limitations.--This type of investigation necessitated the study of a production process and, as a result, differed considerably from a study performed in the laboratory. For a laboratory problem, equipment can be designed to eliminate, or make constant, variable factors that could otherwise preclude the attainment of objectives.

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[3]The first vertical extrusion process was developed in Germany by Otto Kreibaum in 1948. There have been a number of horizontal and vertical extrusion units developed in the United States since that time.

This is not true when investigating an established production method. Among other things, limitations are imposed by machinery design and operation size. These restrictions may introduce innumerable variates that would reduce the efficiency of an investigation. If, however, the limiting factors can be suitably evaluated, some process variables, resulting from design, may be appraised and their importance determined.

The Extrusion Process

Press type.--Horizontal and vertical extruders are the two basic units now in use. They have a similar method of board production, however, as the names indicate, press orientation is different. The Chipcraft vertical extrusion unit was developed in this country by the Chipcraft Corporation of Morristown, Tennessee. This was the unit installed at the plant where the study was conducted. The following description of the production method is included to help the reader of this paper more fully appreciate the intracacies and uniqueness of the process. Reference to the schematic diagrams in Figures 1 and 2, pages 7 and 11, will be helpful in following the process description.

Raw Material

Chip production.--Wood of varying forms is placed on a conveyor leading to a knife hog(1-a), or chipper, where it is reduced to large pieces approximately one-half to one and one-half inches long and of variable widths.

From the chipper, the material is carried on a conveyor to a large hammer mill hog(1-b). Here the large chips are reduced by the beating and crushing action of the hammers to smaller particles.

After passing through the hammer mill hog, the moist[4] chips are conveyed to an in-process storage bin(1-c), from which they enter one end of a Hiel rotary drier(1-d). The air in the drier is heated by means of an oil system which maintains temperatures in the drier from 900 to 1,200 degrees Farenheit. The cylindrical drier rotates and eventually moves the particles to the opposite end, where the dried chips are removed by an air cyclone (1-e). Particle moisture content at this point is approximately 4 percent.

The particles pass from the cyclone into another hammer mill(1-f), which further reduces them in size. From this point the chips are carried, by means of an air conveyor, to a pair of Gyroset vibrating, inclined screens(1-g). Each screen is twelve feet long and four feet wide. They are placed one above the other, with a one and one-half foot space separating them. The upper

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[4]At this point the particles may possess a moisture content ranging from 8 percent up to, and above, 30 percent, depending on the form of wood being processed.

screen has large openings (five meshes per inch). As a result, most of the particles pass through it onto the lower screen. The large chips that do not pass through the upper screen are carried to the lower end, where they fall into a third hammer mill(1-h) and are further reduced in size. They are then recirculated through the air system and again fall onto the upper screen. The lower screen has smaller openings (ten meshes per inch) through which the fine material passes and is carried off as waste. Chips that do not fall through the lower screen come from the end of the screen and are conveyed to a silo(1-i) for storage.

Resin.--Urea formaldehyde resin is used as a bonding agent for the particle board. Commercially prepared resin comes to the plant in barrels. Solids content of the resin is 66 percent.

Catalyst.--A catalyst recommended by the glue manufacturer is added to the resin prior to the mixing operation.

Lubricant.--Powdered zinc sterate, a wood lubricant in dry form, is added to the chips during the mixing operation.

Resin Application

Batch control.--Particles are taken from the silo by a normal silage unloader and raised by a screw and air conveyor into a metering and weighing tank(1-j) located next to the silo and directly above the mixer. When the proper amount of chips has been placed in the tank, the conveying system from the silo is automatically stopped. The mechanism was set to cut out at 190 pounds.

Trap doors, operated by compressed air, compose the bottom of the weighing tank. When ready for a batch of chips, the doors are opened and the chips fall directly into the mixer(1-k).

Mixing.--The mixer is a semi-circular tank containing a shaft with attached beaters. The shaft is belt driven by an electric motor. A previously prepared glue mixture, composed of resin, catalyst, and water, is placed in a receptacle. A hose connects the receptacle to a pipe attached to the edge of the mixer. Eight spouts extend from the pipe over the chips in the mixer. As the agitator rotates and churns the chips, lubricant is added and resin mix is pumped from the receptacle, through the spouts, and onto the chips. The chips are churned and mixed for five minutes. Intended moisture content of the mixed particles is between 6 and 8 percent.

Chip Flow and Distribution

Chip flow.--The resin coated chips are now ready to be pressed into a board. Trap doors are opened, the chips fall through the bottom of the mixer, and are taken to a

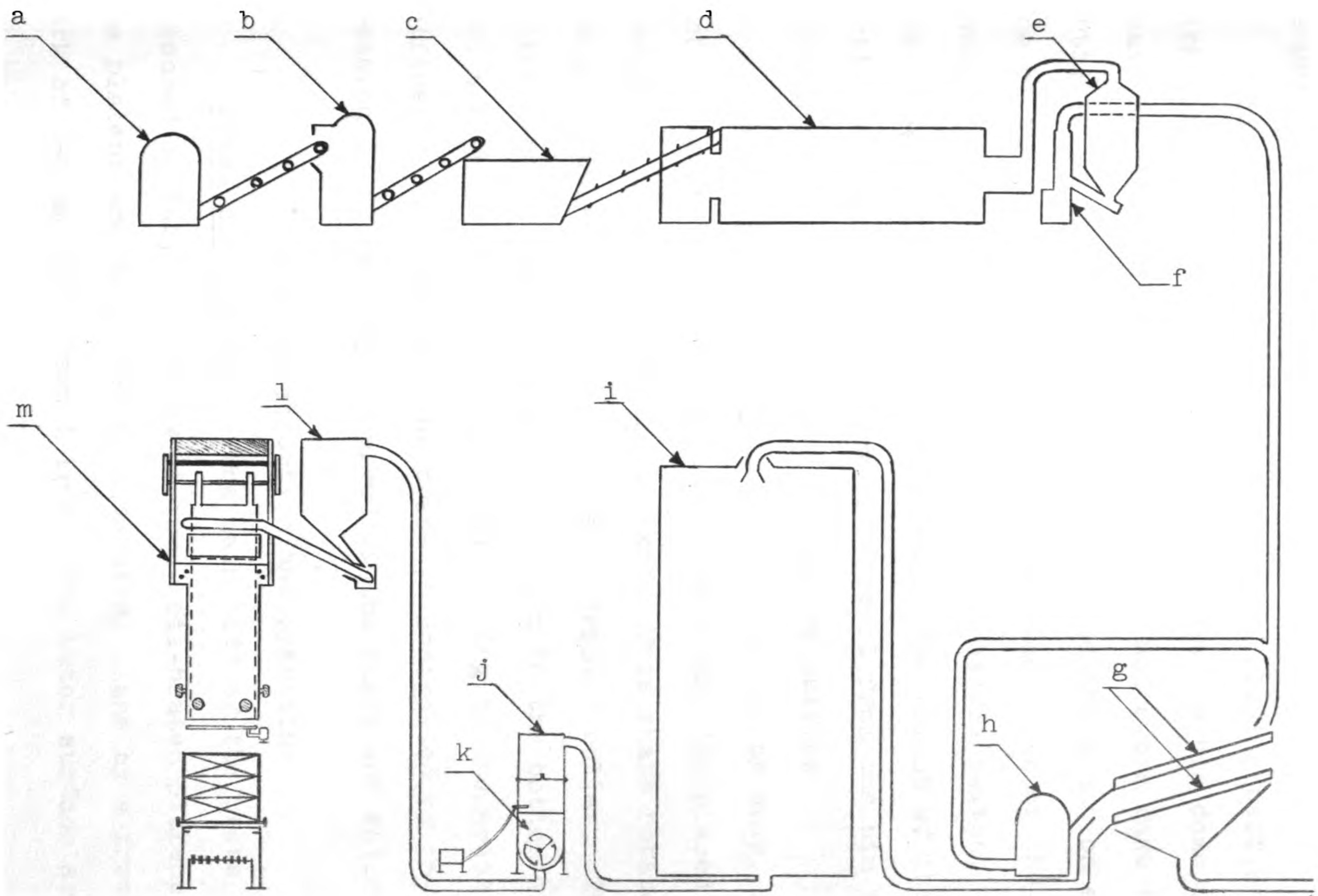

Fig. 1. Schematic Diagram of the Vertical Extrusion Process Operations

storage bin(1-1) located in the top of the building, next to the press(1-m).

In the bottom of this bin are oscillating baffles which, when actuated, sift the chips from the bin down to a pair of bucket conveyors. The bucket conveyors take the particles to distributing troughs located above and on each side of the press. The troughs extend the width of the press and taper toward the bottom. A pressure switch, located in each trough and actuated by the weight of the particles, regulates the flow of material from the bin to the troughs by stopping and starting the baffles.

Particle distribution.--At the bottom, or apex, of each trough is a horizontal shaft which has pins placed through it perpendicular to the axis. This shaft rotates and distributes the particles over a grooved roller. The roller carries chips through an opening in the bottom of each trough and onto a metal chute leading to the press orifice. Chip feed into the press is controlled by increasing or decreasing the speed of the shaft and roller.

Press Construction and Operation

Press construction.--The main body of the press is composed of two, 14 foot by 52 inch, oil-heated platens(2-a). The platens are supported in a vertical plane by a framework of I-beams and channel iron. The outer surface area of each platen is reinforced with I-beams, which are cross-braced and welded into channel iron along the edges.

The platens are heated by means of a thermostatically controlled oil system, which pumps hot oil through them.

The press is held together by means of bolts and pneumatic cylinders. Four bolts, two at each edge, pass through the entire upper framework and exert pressure at the top of the press. These bolts are located near the edge of the platens and are either one and one-fourth or two inches in diameter. The one and one-fourth inch bolt (2-b) passes through the edge of the platens, while the two inch bolt(2-c) is placed a little to the outside. By means of a sixteen inch diameter air cylinder(2-d), located on each lower corner of the platens, one hundred pounds per square inch is exerted to hold the lower end of the press together.

Desired board thickness is attained by placing spacer bars(2-e) along each edge of the press. Each spacer is hung on the one and one-fourth inch bolt that passes through the upper framework and is held in place by the restraining devices of the press. In addition to these pressure devices, a small air cylinder, attached to each spacer bar exerts a force to hold the bar in the vertical plane.

Stainless steel cauls(2-f) cover the inside of the platens for a distance of twelve feet down the length of the press. A shear plate(2-g), that is bolted into the top of each platen, holds the cauls in place and serves as protection for the cauls. These shear plats comprise the top of the press and form the orifice into which the chips fall from the distributing troughs.

Press operation.--Chips are forced into the press by the reciprocating action of the ram(2-h) and the plunger (2-i) affixed to it. The ram is actuated by a rod and cam system that is belt driven by a twenty horse-power electric motor. The plunger is held to the ram with machine screws to facilitate changing when a different board thickness is desired. The ram works continuously at one hundred twenty strokes per minute. The length of each stroke is one and one-half inches.

Directly above the press opening, riding on the shear plats, are two horizontal bars (2-j) that are synchronized with the ram to move in and out as the ram moves up and down. As the ram moves up, the bars move inward to squeeze the accumulated chips over the press opening. Then, as the ram moves down, the bars move back, allowing the plunger to punch the chips down into the press and also allowing more chips to accumulate.

With each downward stroke of the ram, a small increment of chips is forced into the press. The resin coated mass of chips passes between the heated platens and is cured into a board.

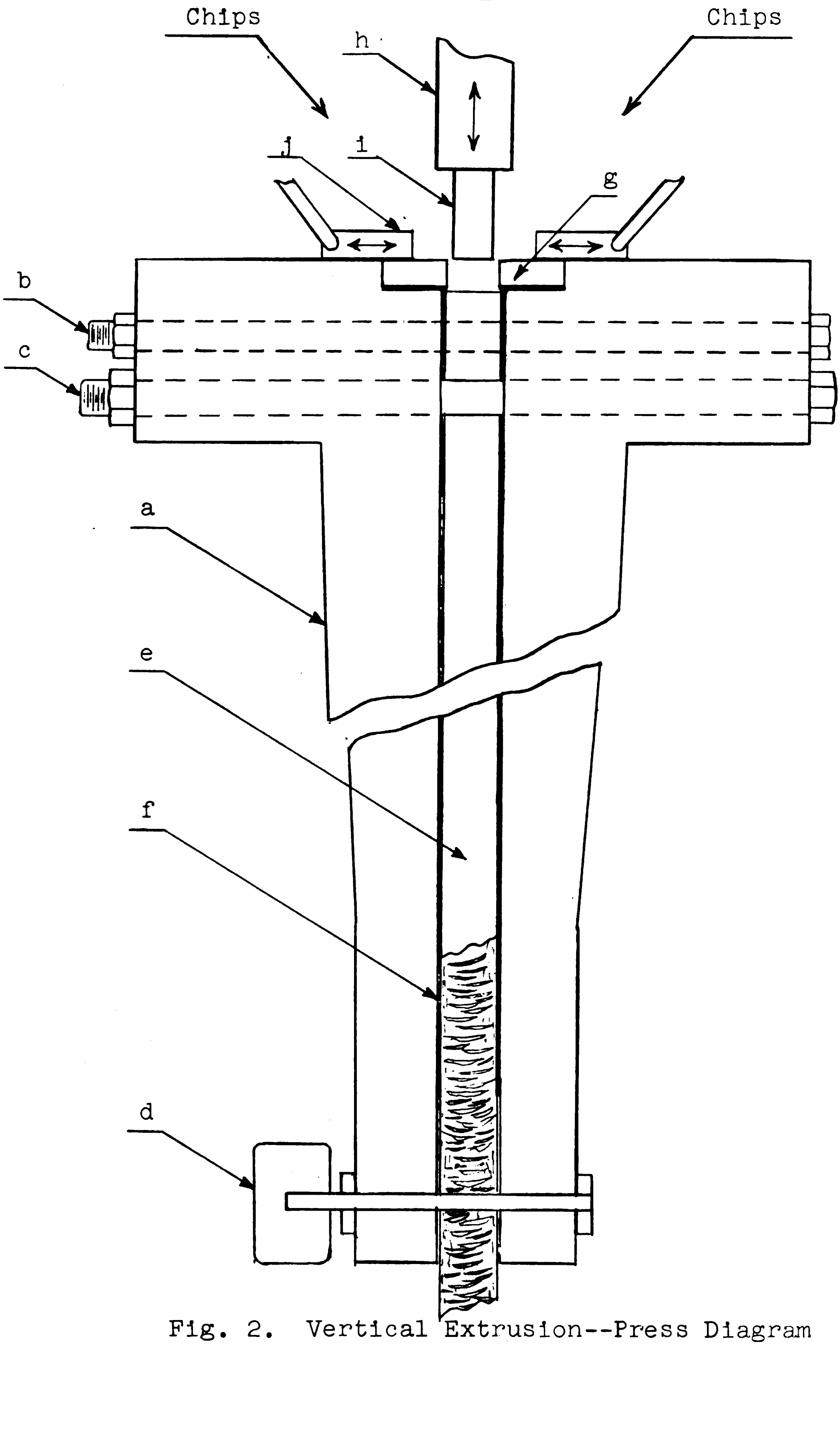

Fig. 2. Vertical Extrusion--Press Diagram

The cured board emerges from the bottom of the press into the arms of a pneumatically operated tiltdown conveyor. When the proper length board has been extruded,[5] a limit switch is actuated and a traveling cut off saw cuts the board to proper length. The cut board drops into the tilt-down conveyor and is carried onto a pile from which it can be removed for storage and shipment or for further manufacture.

Product Description

Thickness and width.--The extrusion unit can be set to manufacture solid particle board ranging in thickness from one-half to one inch. Width of the board, as it emerges from the press, is 49 inches.

Appearance.--Figure 3, page 13, illustrates the physical appearance of solid extruded particle board. The face (3-a) is composed of many small chips packed together in varying directions. The cross sectional area, perpendicular to the extrusion direction(3-b), shows a similar variable pattern; however, the particles are larger than those on the face. The edge cut parallel to the extrusion direction (3-c), exhibits particle orientation more or less perpendicular to the face.

On close examination of the surfaces, small spaces, or voids, are apparent. The face seems to have fewer voids

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[5]The boards may be cut to any desired length, from two to twelve feet.

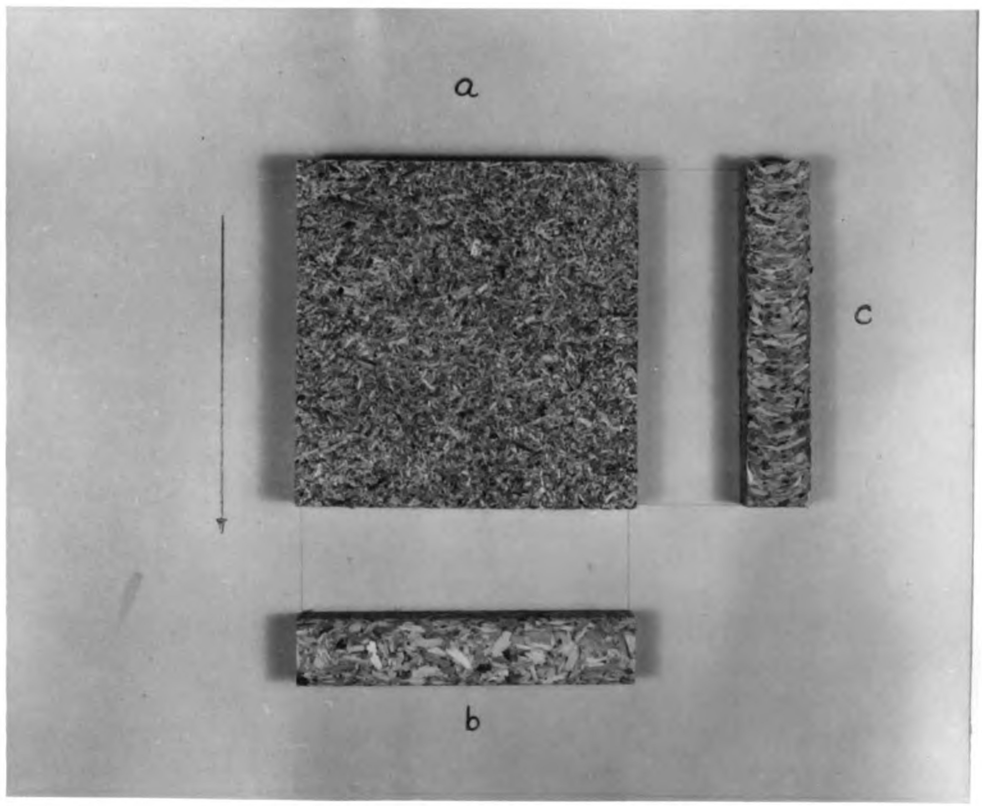


Fig. 3. Face and Edge Views of Vertically Extruded Particle Board

than the edges due to the fact that fine particles have accumulated to occupy the small openings between larger particles.

II. VARIABLE FACTORS

Machinery

Chip production.--Particle size, shape, and quality are determined by processing equipment in the particle production line. The physical character of chips, comprising a resin bonded particle board, has been shown to have a considerable influence on properties and characteristics of that board. Most studies in this area have been conducted on flat pressed boards; however, it is felt that many of the principles brought out in these investigations can be related to the character of board produced by the extrusion process.

Some studies point to fiber quality as a determinant of board strength. H. D. Turner (2) has found that fiber damage is one of the primary causes of a poor bond between particles. In the hammer milling process, not much can be done to prevent fiber damage. F. Kollman (3) feels that during chip processing, wood that is too dry tends to produce an abnormal amount of fine material, while wood that is too wet has a tendency to tear and open up the pores. The Wood Particle Board Handbook (4) estimates that approximately 30 percent moisture content is the desired range for chip manufacture.

That particle size has an effect on board strength was proven by H. D. Turner (2). In his work on flat pressed boards, he found that chips with a high length-thickness ratio produced a stronger particle board. Other studies of similar scope show that small chips do not produce high strength boards in the lower density ranges.

Particle size is the primary variable governing efficient resin distribution. Small chips have a considerably greater surface area per unit of weight than do large chips. A given amount of binder can effectively cover a given area and still produce the strongest bond attainable between particles. This would indicate that, with resin content remaining the same, greater strength values in every type particle board can be obtained by developing an optimum size chip.

Mixing.--N. A. DeBruyne (5) feels that a thinner glue line creates a stronger joint. If resin could be distributed evenly over every chip and the particles laid uniformly side by side and end to end, a very desirable particle board could be produced. This is not practical nor possible in an extrusion process.

In most mixing processes, resin distribution is usually not perfect; however, a more even covering can be accomplished by use of spraying apparatus. The variables encountered during the mixing process are: resin viscosity, atomization, particle and resin moisture content, and the particle surface area exposed. At this plant, spraying equipment was not employed. The resin mix was pumped onto the churning chips in eight solid streams. Although some transfer of resin from one particle to another undoubtedly took place, it is felt that the character of the mixing operation would result in variable resin concentration throughout each batch.

Particle moisture content is normally raised a certain amount when the resin mix is applied. The increase, beyond that effected by moisture in the resin, may be partly controlled by additional amounts of water.

Pressing.--In an extrusion press, the material is compressed parallel to the length of the board. The pressure is developed by the ram which exerts a force equal in magnitude to the sum of frictional forces between the material and the press platens. Pressure is therefore a function of normal forces resulting from the coefficient of friction between the particles and the steel platens and the length of the press. Pressure may also depend on the area through which the force acts or the cross sectional area of the board.

Curing time, of the adhesive, will depend on press temperature. For a given press length and extrusion rate, the temperature must be high enough to solidify the material before it leaves the press. The loose moist particles, entering the press, are compressed and cured and leave the press in an aggregate form. Intermediate stages of curing will be found at different locations along the press. The normal acting forces will be affected at different stages of curing. One would expect that the cured board would create less frictional force between the platens and particles. If temperature were increased, curing time would be decreased along with friction thereby causing a less dense board to be produced.

Particle moisture content will also affect curing rate and the coefficient of friction which, in turn, would have some affect on pressure and board density.

Product

Thickness.--The spacers used determine board thickness. Any factor that may cause deviation from desired press form may be considered a variable affecting thickness. Among these factors are holding devices, spacer bars, heat, and forces exerted by the flowing chip mass.

Density.--In particle board manufacture, the degree of compactness is determined by pressure exerted and compression affected. Some variables related to pressure have been discussed. Other factors must also be considered. Because of plasticity and hardness characteristics, high density wood may produce a lower density board than softer, less dense wood, when formed under equal pressure (4). For similar reasons, larger particles will compress less than smaller ones. Chips with a lower moisture content are less pliable than particles having a higher moisture content, and therefore under most circumstances, will form less compact boards.

Strength.--Some factors affecting strength have been partly discussed in the machinery section of this chapter. It is difficult to interpret all of the interrelated variables that may have an affect on strength properties. Particle orientation will undoubtedly have some result and according to Turner (2), particle size also affects strength. H. C. L. Miller (6) feels that the type of wood used for Chipcore has no direct affect on the strength of the boards produced. He further states that density is much more indicative of strength properties than is the amount of resin used.

It appears that particle orientation and size, and the factors affecting density are the main contributing variables to board strength. This may be so in that fiber orientation determines the strength properties of particles with regard to directed stresses, particle size is a determinant of resin coating, and increased density necessitates a closer contact between particles and therefore a better bond.

Summary

This discussion illustrates the rather complex nature of the extrusion process and the difficulties encountered in any attempt to relate the properties of the extruded product to process variables.

III. INVESTIGATION OBJECTIVES

Definition of the Problem

The purpose of the investigation was to analyze the major factors that determine board properties. The external examination of the process provided a basis for selecting variables to be studied.

Objectives

Wood species.--Although it was not to be related to board properties, a sample to indicate species used in manufacture was felt to be important.

Particle size.--Chip size was considered an important variable characteristic. An investigation of the causes for particle variation was conducted.

Thickness.--Board thickness was analyzed in an attempt to isolate reasons for variation.

Density.--A study of density was undertaken to determine the effect of raw material characteristics and process variables on density.

Strength.--The effect of particle size on strength was also investigated.

Process control.--Use of the acquired results for suggesting a process control technique was felt to be a fitting culmination for the study.

IV. METHODS OF INVESTIGATION

Sample Size

Production capacity.--The vertical extrusion unit averages two linear feet of board per minute. On a continuous production basis, this would be 120 feet of extruded particle board per hour or 960 linear feet per eight hour day, excluding breakdowns and other delays.

Board selection.--Six normally produced boards eight feet long were taken over a period of two days, during which time the extrusion unit manufactured approximately 720 linear feet. The samples were selected at one and one-half hour intervals and composed 6.6 percent of the production for the period.

Another six boards were taken in one day from a production nearing capacity. This second sample comprised 4.4 percent of the total production. Included among these boards were two specimens composed of chips from which fines had been removed. This sample was used exclusively for comparative study of particle size and its effect on strength. Control boards from normal production were selected at one hour intervals before and after the specially manufactured specimens had been processed.

Number of test specimens.--Six bending specimens and three tension perpendicular to the surface specimens were taken from each board, with two exceptions. For comparative purposes, it was decided that twelve bending specimens should be taken from the two boards in the second series which were composed of screened particles. Nine density specimens were also taken from each board. To represent the entire width, samples were selected at random from three areas across the board.

Particle samples.--Samples of chips were selected at different points along the production line. Five samples were collected from each of three locations for comparative purposes.

Other particle samples were taken from the distributing mechanism in an effort to determine chip distribution. These specimens were taken on each side of the press and numbered eighteen in all.

Control of Variables

Moisture content.--An attempt was made to measure chip moisture content after mixing and to relate any abnormal variation of this factor to board characteristics. It was found that moisture content was held within very small limits--5.8 percent to 7.8 percent. To associate the gross characteristics being studied to these small moisture content variations in a production situation was improbable. However, moisture content of the mixed chips, composing each of the sample boards was taken to make certain that moisture content did not vary abnormally.

Resin, catalyst, and lubricant.--During the study, two different brands of resin were used with two different types of catalyst. Resin content, catalyst, and lubricant were varied by the manufacturer in an attempt to control the product. These values were recorded for each board selected.

In the first six boards, variation was extremely high. Resin, catalyst, and lubricant were maintained at the same level so that comparative tests could be run on the second group of boards.

Particle size.--A specimen of the chips entering each board was taken from the distributing conveyors above the press. Percentages of particle sizes were recorded for each sample. Control of raw material was maintained by allowing the distribution system to empty before introducing the particles that had undergone fine removal.

Tests Performed

Strength tests.--In an effort to discover strength determinants, flexural bending and tension perpendicular to the surface tests were performed on samples during the study. The tests were conducted in accordance with tentative specifications set up by the National Woodwork Manufacturers Association (7). A description of these tests appears in the Appendix.

Density tests.--Two sets of density values were recorded for each board selected during the investigation. One set was used to determine density variation between and within different boards. The other set was a measure of density for specimens that had undergone bending tests. A description of the method for deriving the density of each set is included in the Appendix.

Thickness.--These measurements could have been taken in a number of ways. It was felt that no negative effects would be encountered by using thickness values attained in one operation for two purposes. Thickness values obtained from density samples were used in the study of thickness variation.

Particle size.--The method of determining particle fractions for comparative tests of chip samples appears in the Appendix.

Wood Species and Forms

General information.--A mixture of species and forms of raw material is used for the production of chips. Although it would have been possible to select and fabricate board from one species and form at a time, this was not felt to be realistic.

The main source of raw wood is from woodlots in the immediate vicinity of the plant. This material is four to eight inches in diameter and is cut into four foot bolts. It is brought to the plant by truck. Aspen comprises the main body of this green wood; however, some of the other hardwood species--oak, maple, birch, and cherry--are also cut. Sawmill slabs and kiln dried blocks of maple and pine are brought to the plant for production into chips. Cured board trimmings, resulting from secondary manufacturing operations, are also reprocessed into chips.

These forms of wood are sent through the chipper, one after the other, in different proportions. As a result of this mixing, it was not possible to determine exact amounts of the type material used in each board. To estimate the proportions of forms and species used, a record of the chipping operation was made.

Procedure.--A tally was made by unit, each unit being one four foot bolt. Relative proportions of slabs, blocks, and edge trimmings were equated by an estimate to the unit of a bolt. Species and form were recorded on a chart, and the relative proportions of each form and species was obtained from the record. Results of these samples appear in Chapter V.

Particle Size

Background information.--Particle size was regarded as a major contributing factor to a number of important board properties. Therefore, its variable character and contributing factors to the variation were studied.

Procedure.--Chip samples were taken at three locations along the production line. First of these was as the particles left the rotary drier. The second was just prior to the screening operation, and the third point was from the conveyor before pressing.

An examination of each operation affecting the chips prior to pressing was also undertaken. Results from the particle samples and the operation investigation can be found in Chapter V.

A Study of Thickness Variation

Background information.--Press setting and the factors affecting variation from desired press form were considered to be the determinants of thickness. To investigate variation, it was necessary to obtain thickness measurements from similar areas of different boards.

Procedure.--Thickness measurements of the density samples taken from each board were used to determine thickness variation. The density samples were cut from three locations across the board. Approximately one inch was trimmed from each board edge and density specimens were then taken from the left, center, and right locations. Four thickness measurements were obtained for each specimen. The average of the four measurements was used in the analysis of thickness. Results and analysis appear in Chapter V.

A Study of Density

Background information.--Particle board density is a consequence of pressure and compression. All factors affecting either of these characters can be related in some way to the ensuing board density. This study was performed in an attempt to relate raw material and process variables to resultant density.

Procedure.--Characteristics of the raw material entering each selected board were measured and recorded. Density samples were taken from the boards in the prescribed manner and the results were analyzed.

Particle distribution was also investigated as a possible source of variation. Particle samples were collected from six locations along the distributing conveyor. Samples were fractionated and compared. The results and analysis of the density study appear in Chapter V.

The Effect of Particle Size on Strength

Background information.--The fact that particle size may affect strength has been discussed. Observations of particles entering the extruded board indicated the presence of an extremely high percentage of fine material. Subsequent chip samples bore this out. A study was undertaken to investigate the effect of particle size on board strength.

Procedure.--A vibrating screen grain cleaner was employed to remove fines from normal chips. A picture of chips before and after fine removal appears in Figure 4. The screen used had twenty meshes per inch. Enough material was screened to compose a normal 190 pound batch. As normal production continued, resin, catalyst, and lubricant were maintained constant.

The screened-particles were placed in the mixer and a proportion of resin, catalyst, and lubricant equal to that used on the normal chips was applied. The particles were placed in the system and boards composed from the screened-chips were procured. Strength values for normal and screened-particle boards were determined and a comparative analysis was performed. Results and analysis of the tests appear in Chapter V.

Process Control

Background information.--Process control was felt to be one of the most profitable applications for the acquired

Before $\frac{1}{2}$ X

After $\frac{1}{2}$ x

Fig. 4. Particles Before and After Fine Removal

results. A dependable control system rests solely on reliable accurate data that is easily obtained and systematically recorded. If the results obtained from the study of variables showed significant influencing characters, a basis for control could be established.

Procedure.--All the acquired data were examined so that influencing factors could be isolated. The correlations between board thickness and density and between density and strength were investigated to establish the relation among the three product variables. Results of the acquired data, used for control bases, and the control charts established from the data appear in Chapter V.

V. RESULTS AND ANALYSIS

Wood Species and Forms

Analysis.--No analysis, as such, was necessary for the sample of species and forms fed to the chipper. The object was to determine relative proportions of species and forms being used for particle production. Similar species and forms were combined and the percentage of the total was computed for each group.

Results.--The following percentages are the results of the sample:

TABLE I

PERCENTAGES OF WOOD SPECIES AND FORMS

Total Units	773	100%
Green Bolts		
Aspen	443	57%
Oak	155	20%
Blocks	155	20%
Slabs and Edge Trimmings	20	3%

Particle Size

Analysis.--The five chip samples taken at three locations along the production line were reduced to fractional percentages. The percentage value of fine particles in each sample was transformed to arc sine times the square root of the percentage (8). An analysis of variance was run on the data.

Results.--This data, combination, transformation, and the analysis of variance can be found in Table II.

The analysis shows a highly significant difference between particle samples with regard to location. Comparison of the averages shows that there is a difference between samples taken after drying and those taken before and after screening. No difference is indicated between particles before and after screening.

The examination of operations in the chip production line revealed a one-half inch mesh screen in the hammer mill after drying and a metal sheet covering all but a thirty inch section of the lower vibrating screen.

Thickness Variation

Analysis.--Average thickness values were recorded for three locations across the board. An analysis of variance was performed on the data to determine whether or not significant differences did exist.

Results.--The values and the analysis of variance data appear in Table III. The measurements show a peculiar pattern of variation from left to right. The left and right edges, within each row, are nearly equal. The center

TABLE II

RESULTS AND ANALYSIS OF FRACTIONATED PARTICLE SAMPLES FROM THE PRODUCTION LINE

Samples	Particle Samples From Dryer--(A) Fractions in Percent					
	1	2	3	4	5	6
I	48.96	32.88	13.49	3.43	0.97	0.24
II	45.48	38.12	12.24	2.82	0.88	0.53
III	53.96	30.00	11.00	2.99	1.18	0.86
IV	49.23	33.11	13.18	3.28	0.79	0.41
V	41.58	35.37	14.98	4.60	2.06	1.40

Samples	Particle Samples Before Screen--(B) Fractions in Percent					
	1	2	3	4	5	6
I	22.87	43.76	18.15	7.50	4.77	2.90
II	25.41	38.55	16.74	9.12	7.10	3.10
III	23.68	36.77	20.54	9.75	5.34	3.92
IV	23.61	35.62	23.32	9.25	4.94	3.27
V	28.78	36.35	18.65	8.36	4.66	3.20

Samples	Particle Samples Before Press--(C) Fractions in Percent					
	1	2	3	4	5	6
I	4.30	48.50	24.60	11.20	7.40	3.20
II	3.00	37.70	33.60	13.80	9.40	2.50
III	2.20	44.60	35.70	10.30	5.60	1.20
IV	5.70	39.90	34.20	12.70	4.96	2.40
V	2.70	38.40	26.10	17.00	8.70	2.60

TABLE II--Continued

Samples	Combining Fractions 4, 5, and 6 Locations		
	(A)	(B)	(C)
I	4.64	15.17	21.80
II	4.23	19.32	25.70
III	5.03	19.01	17.10
IV	4.48	17.46	20.06
V	8.06	16.22	28.30

Samples	Transformation to Arc Sine $\sqrt{\text{percentage}}$ Locations		
	(A)	(B)	(C)
I	12.45	22.93	27.83
II	11.90	26.08	30.46
III	12.98	23.85	24.43
IV	12.22	24.70	26.60
V	16.50	23.75	32.14

Analysis of Variance Results

Source of Variation	Degrees Freedom	Sums of Squares	Mean Squares	F
Total	14	678.56		
Locations	2	619.67	309.84	68.85**
Samples	4	22.87	5.72	1.27
Error	8	36.02	4.50	

**Significant at the 1% level

is thicker in all cases. The analysis of variance for each board indicates a significant difference between locations in all boards. A difference is also revealed between rows in four out of the six boards.

Study of Density

Analysis.--Two different types of data were collected during the density investigation. The density specimens were analyzed by means of a three factor analysis of variance to test differences within and between boards. A t-test was used to compare the relative proportions of particle size entering the press at three locations.

Results.--The computed values for density specimens by location is followed by the analysis of variance table for the data. (See Table IV.)

An analysis of each board indicated no significant difference within locations in the boards. A highly significant difference was found between the locations. After grouping, differences were indicated between the boards and between the locations. A test of the values for locations in order of density from highest to lowest, produced the following ranking; right, left, center.

Data and results of the analysis for chip fractions entering the press at three locations appear in Table V. The results from analysis indicate that the particles on the

TABLE III

RESULTS AND ANALYSIS OF THICKNESS VALUES

Board No.	Thickness at Three Locations Inches		
	Left	Center	Right
I	0.638	0.659	0.637
	.635	.652	.634
	.624	.637	.620
II	.607	.612	.597
	.601	.610	.593
	.598	.606	.593
III	.598	.603	.595
	.596	.605	.592
	.594	.601	.589
IV	.607	.620	.606
	.608	.622	.608
	.609	.623	.609
V	.598	.610	.598
	.599	.612	.598
	.599	.609	.597
VI	.589	.598	.587
	.586	.595	.587
	0.583	0.592	0.585

Analysis of Variance Results for Each Board[1]

Source of Variation	Degrees Freedom	Sums of Squares	Means Squares	F
I Total	8	1180		
Locations	2	654	327	72.66**
Rows	2	508	254	56.44**
Error	4	18	4.5	

[1]0.580 was used as a provisional mean for computations.

**Significant at the 1% level

TABLE III--Continued

	Source of Variation	Degrees Freedom	Sums of Squares	Mean Squares	F
II	Total	8	409		
	Locations	2	337	168.50	67.40**
	Rows	2	62	31.00	12.40*
	Error	4	10	2.50	
III	Total	8	220		
	Locations	2	186	93.00	46.50**
	Rows	2	26	13.00	6.50
	Error	4	8	2.00	
IV	Total	8	394		
	Locations	2	383	191.50	766.00**
	Rows	2	10	5.00	20.00**
	Error	4	1	0.25	
V	Total	8	304		
	Locations	2	298	149.00	198.66**
	Rows	2	3	1.50	2.00
	Error	4	3	0.75	
VI	Total	8	195		
	Locations	2	156	78.00	52.00**
	Rows	2	33	16.50	11.00*
	Error	4	6	1.50	

**Significant at the 1% level
*Significant at the 5% level

TABLE IV

RESULTS AND ANALYSIS OF DENSITY SAMPLES

Board No.	Density[1] at Three Locations		
	Left	Center	Right
I	54.68 55.63 54.32	52.85 51.97 52.47	60.37 61.25 60.12
II	50.33 49.60 48.79	48.48 48.81 49.55	54.74 54.81 54.27
III	51.89 51.99 50.74	50.79 49.18 50.69	60.64 59.87 58.76
IV	56.71 58.39 55.25	51.04 50.56 50.67	61.80 61.67 63.59
V	50.55 50.84 52.34	47.15 48.53 47.82	57.97 57.56 59.16
VI	50.21 50.38 49.33	48.61 48.74 48.01	56.98 56.68 56.07

Analysis of Variance Results[2]

Source of Variation	Degrees Freedom	Sums of Squares	Mean Squares	F
Total	53	1064.54		
In Bd. Loc.	12	6.39	0.53	0.86
Boards	5	238.11	47.62	76.81**
Locations	2	757.76	378.88	611.10**
Bet.Bds.x Loc.	10	47.41	4.74	7.65**
Error	24	14.87	0.62	

**Significant at the 1% level

[1]Specific weight in pounds per cubic foot.

[2]50.00 was used as a provisional mean for computations.

TABLE V

RESULTS AND ANALYSIS OF FRACTIONATED PARTICLE SAMPLES FROM THREE PRESS LOCATIONS

Position[1]	Sample I Fractions in Percent					
	1	2	3	4	5	6
L-N	4.05	44.24	30.10	10.52	7.54	3.36
L-S	2.76	44.09	31.48	12.17	6.52	2.96
C-N	4.86	53.50	29.90	8.31	2.70	0.71
C-S	2.51	37.21	37.03	13.10	7.79	2.33
R-N	4.68	50.96	30.16	8.87	3.68	1.64
R-S	0.60	26.78	32.87	16.63	15.66	7.50

Position[1]	Sample II Fractions in Percent					
	1	2	3	4	5	6
L-N	2.04	32.82	33.87	16.44	11.33	3.51
L-S	5.44	40.87	32.61	13.24	6.61	1.22
C-N	5.89	49.45	32.30	8.53	3.42	0.41
C-S	5.15	48.65	33.24	8.78	3.49	0.69
R-N	4.37	45.95	33.57	10.38	5.15	0.58
R-S	1.32	25.56	34.27	21.69	13.02	4.13

Position[1]	Sample III Fractions in Percent					
	1	2	3	4	5	6
L-N	2.38	41.21	33.73	13.73	6.74	2.20
L-S	2.94	42.87	32.46	12.46	7.47	1.80
C-N	3.61	49.30	33.01	9.00	4.19	0.89
C-S	2.94	46.84	30.97	11.68	5.51	2.07
R-N	4.98	47.48	33.42	9.17	3.81	1.13
R-S	0.65	25.24	31.31	21.58	15.09	6.12

[1]L=Left, C=Center, R=Right; N=North, S=South

TABLE V--Continued

Combined Fractions 1,2,3, N and S for Each Position Within Samples[1]

Sample No.	Position		
	Left	Center	Right
I	78.45	82.51	73.03
II	73.82	87.34	72.52
III	77.79	83.34	71.54

Analysis

$$t = \frac{\bar{d} - 0}{s_{\bar{d}}}$$

Left With Right

$$t = \frac{4.32}{1.52} = 2.84$$ No significance at 2 DF

Center With Right

$$t = \frac{12.03}{1.54} = 7.81^{*}$$ Significant at 5% level

Center With Left

$$t = \frac{7.71}{2.93} = 2.63$$ No significance at 2 DF

[1]Totals divided by 2.

$\bar{d}$ Average difference between locations in samples.

left are not significantly different from those at the center or right. The fractions at the right location are different from those at the center.

The Effect of Particle Size on Strength

Analysis.--Modulus of elasticity and modulus of rupture values, for the bending samples from controlled variable screened and normal chip boards, were analyzed to determine the correlation between density and strength. The regression line of strength on density was plotted for each group of sample values when applicable. Where no correlation was evident, the average value was plotted. Comparable estimated strength values, for normal and screened-particle boards, were compared by means of a t-test.

Values from tests of tension perpendicular to the surface were also determined and analyzed by means of analysis of variance.

Results.--Data for values derived from bending specimens of the normal and screened chip boards appear in Tables VI and VII. Each set of tables is followed by a graphical representation of the regression analysis for data; Figures 5, 6, 7, and 8.

There was no correlation between strength values and density in the direction of extrusion for boards produced from normal particles. The normal boards did show

TABLE VI

FLEXURAL BENDING VALUES AND CORRELATION-REGRESSION ANALYSIS RESULTS PARALLEL TO EXTRUSION

Normal Boards		
Density Lbs/Cu. Ft.	Modulus of Elasticity 1000 psi	Modulus of Rupture psi
45.18	33	259
42.77	21	163
48.94	20	224
46.13	30	297
40.91	34	255
39.70	32	231
37.83	25	189
42.00	32	213
48.38	40	275
46.84	20	216
42.39	28	238
42.02	20	212

r for MOE[2] = -0.0049

Average MOE[1] = 28.50

r for MOR[2] = 0.06

Average MOR[1] = 231.00

[1]No correlation apparent so averages were computed.

[2] r Correlation coefficient

TABLE VI--Continued

Screened-Particle Boards		
Density Lbs/Cu. Ft.	Modulus of Elasticity 1000 psi	Modulus of Rupture psi
47.82	76	768
61.27	186	1775
39.20	66	532
44.69	59	540
47.40	51	478
42.70	71	601
44.03	35	386
47.46	65	571
47.73	54	501
45.18	38	417
34.87	40	368
40.60	47	521

r for MOE[2] = 0.805

Equation for estimating MOE[1]

$$y = -191.50 + 5.72(x)$$

r for MOR[2] = 0.826

Equation for estimating MOR[1]

$$y' = -1593.49 + 48.95(x)$$

[1]x the independent variable, y and y' the dependent variables.

[2] r Correlation coefficient

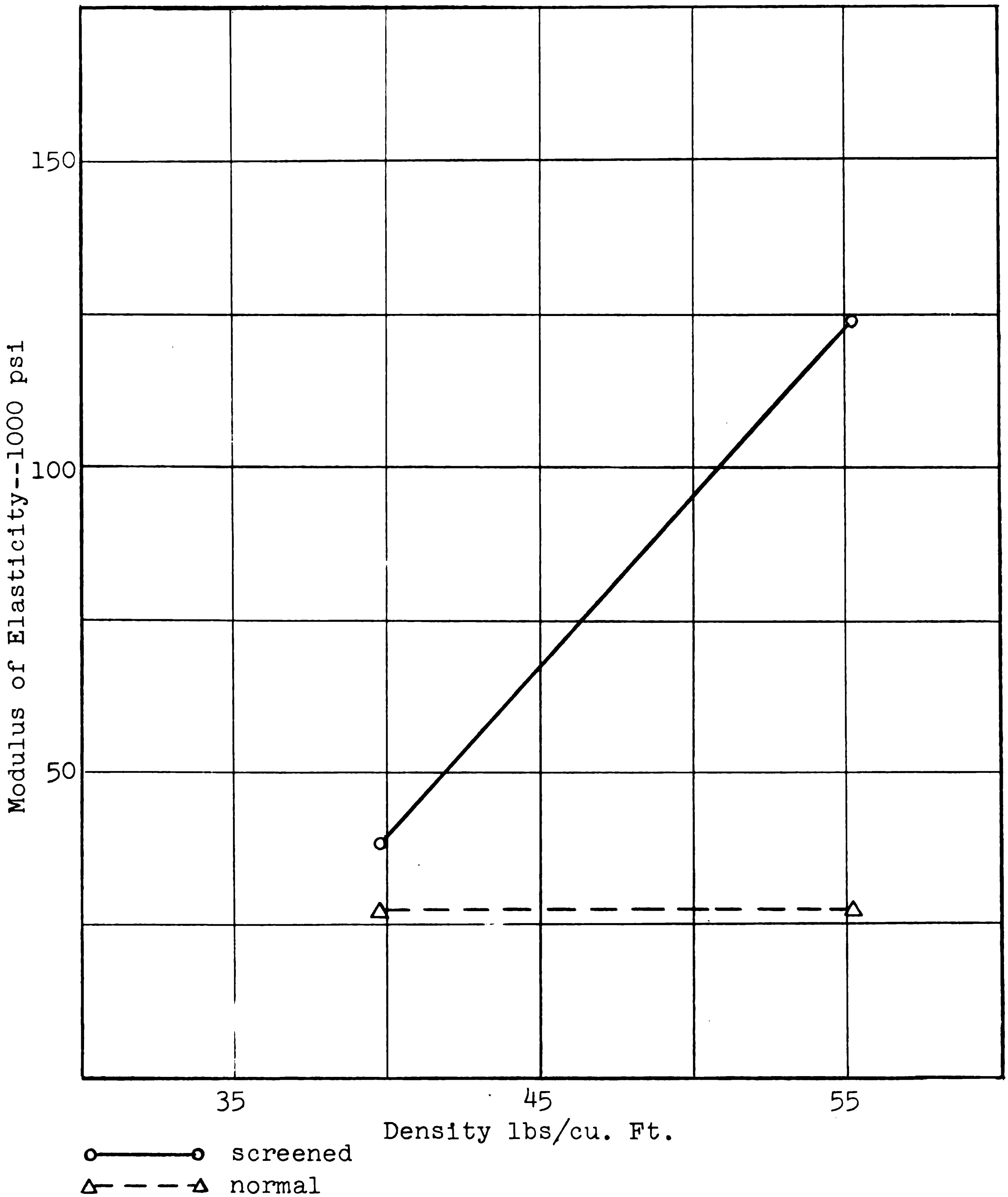


Fig. 5. Graph of Estimated Modulus of Elasticity Parallel to Extrusion Direction

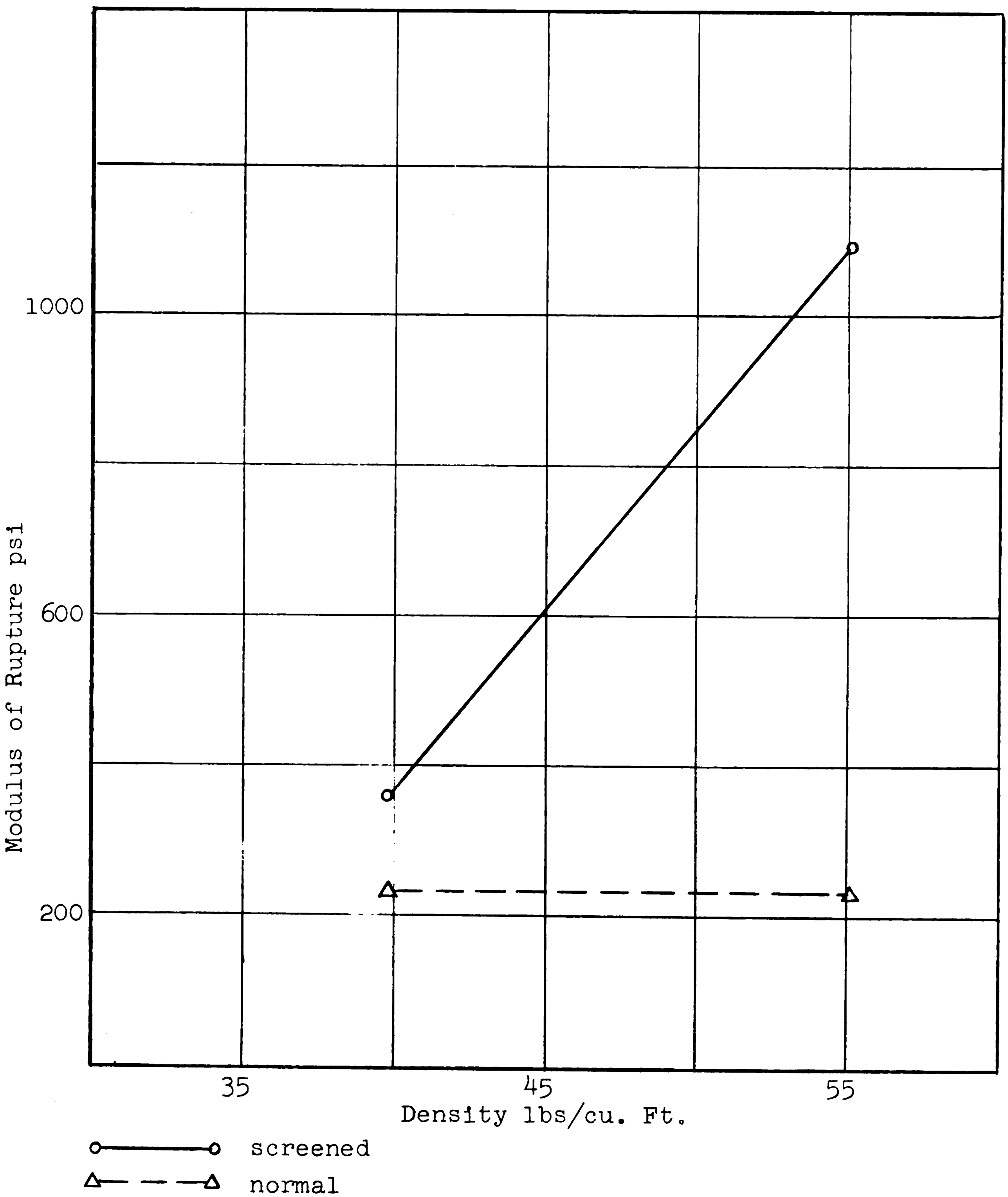


Fig. 6. Graph of Estimated Modulus of Rupture Parallel to Extrusion Direction

TABLE VII

FLEXURAL BENDING VALUES AND CORRELATION-REGRESSION ANALYSIS RESULTS PERPENDICULAR TO EXTRUSION

Normal Boards		
Density Lbs/Cu. Ft.	Modulus of Elasticity 1000 psi	Modulus of Rupture psi
44.04	239	1454
44.06	203	1302
39.37	141	661
35.55	124	683
41.33	159	1159
41.83	210	1409
42.63	241	1574
40.39	168	961
35.37	125	622
36.18	106	611
42.28	177	1093
44.05	230	1556

r for MOE[2] = 0.805

Equation for estimating MOE[1]

$$y = -350.76 + 13(x)$$

r for MOR[2] = 0.826

Equation for estimating MOR[1]

$$y' = -3081.43 + 102.78(x)$$

[1] x the independent variable, y and y' the dependent variable.

[2] r Correlation coefficient

TABLE VII--Continued

Screened-Particle Boards		
Density Lbs/Cu. Ft.	Modulus of Elasticity 1000 psi	Modulus of Rupture psi
58.10	608	4184
63.39	741	5772
41.79	286	1869
54.04	376	3152
39.58	210	1260
54.38	437	3102
38.78	211	1343
38.80	232	1092
46.30	403	2823
40.00	292	1704
53.40	505	3920
38.66	216	1188

r for MOE[2] = 0.949

Equation for estimating MOE[1]

$$y = -489.88 + 18.33(x)$$

r for MOR[2] = 0.969

Equation for estimating MOR[1]

$$y' = -4969.24 + 160.53(x)$$

[1] x the independent variable, y and y' the dependent variables.

[2] r Correlation coefficient

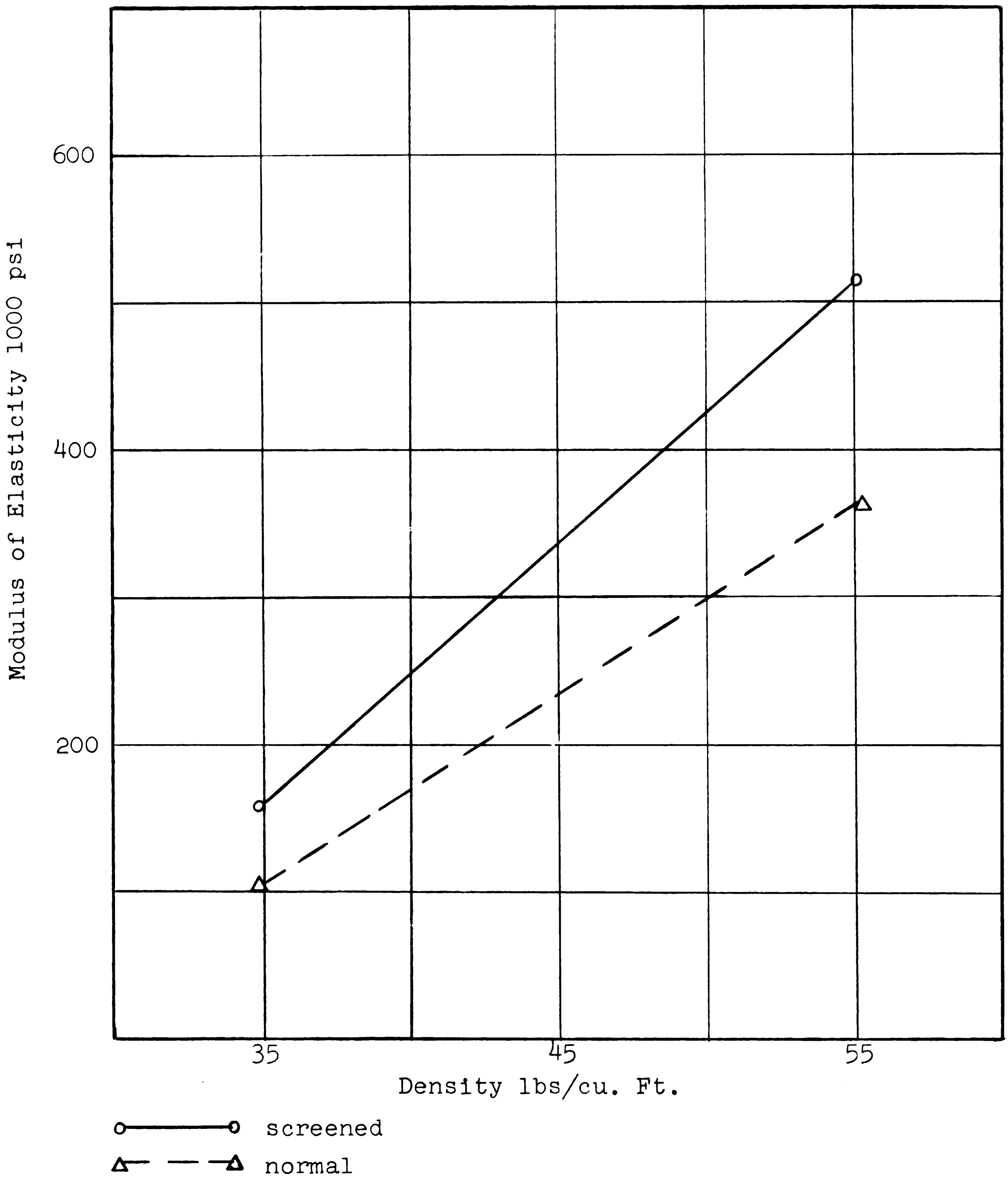


Fig. 7. Graph of Estimated Modulus of Elasticity Perpendicular to Extrusion Direction

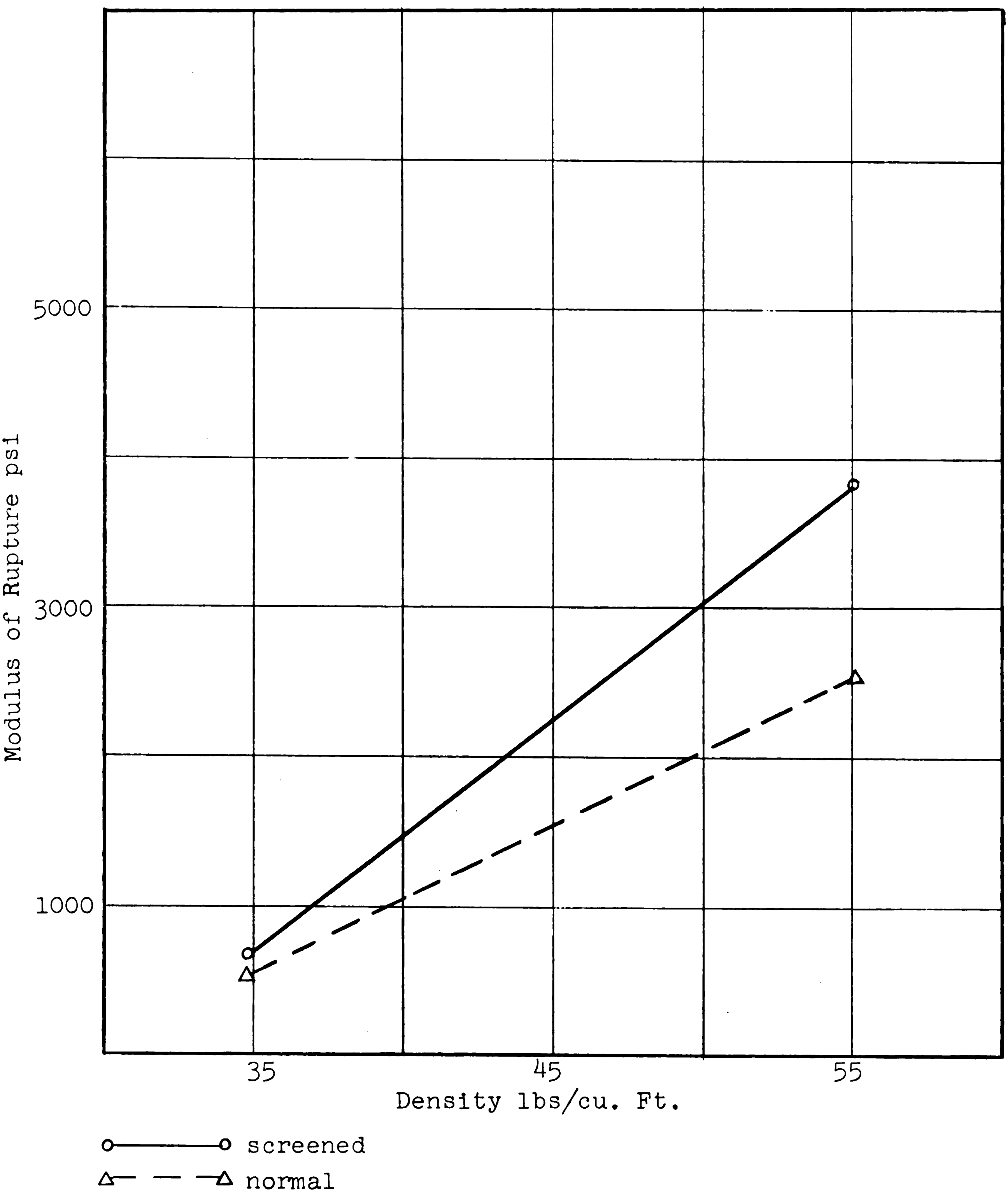


Fig. 8. Graph of Estimated Modulus of Rupture Perpendicular to Extrusion Direction

a significant correlation between the variables perpendicular to the extruded direction. Specimens from screened-particle boards indicated a significant correlation between strength and density in both directions. Table VIII shows the estimated strength values compared at 45 pounds per cubic foot. Boards composed of screened material were significantly stronger in all cases.

Table IX indicates results from the tension tests and the analysis of variance data for the values. The analysis indicates that the screened-particle boards are significantly different from the normal boards.

Process Control

Analysis.--An Examination of the acquired results indicated that particle size is an important strength determinant. Therefore, chip control is also important. The analysis of strength and density showed a significant correlation. A further examination of density and thickness was accomplished by means of correlation analysis.

Results.--Percentages of small particles from samples before and after screening were used to construct a chip control chart. The data and computations for the particle control chart, Figure 9, appear in Table XI.

The thickness and density values, plus the correlation coefficient between the two factors, appear in Table X.

A significant relation is indicated between the variables strength and density, and the variables density and thickness. Because of the inter-relations among the three variables, thickness was chosen as the most easily obtainable factor. Data and computations for construction of the thickness control chart in Figure 10 can be found in Table XII.

TABLE VIII

RESULTS OF COMPARATIVE TESTS BETWEEN ESTIMATED STRENGTH VALUES OF NORMAL AND SCREENED-PARTICLE BOARDS

Modulus of Elasticity Parallel			
Board Type	MOE[2]	Std. Error[1]	t
Normal	28.50	1.79	4.07**
Screened	65.90	29.09	

Modulus of Rupture Parallel			
Board Type	MOE[2]	Std. Error[1]	t
Normal	231.00	10.68	33.05**
Screened	609.26	222.17	

Modulus of Elasticity Perpendicular			
Board Type	MOE[2]	Std. Error[1]	t
Normal	234.24	24.89	2.65*
Screened	334.51	68.07	

Modulus of Rupture Perpendicular			
Board Type	MOE[2]	Std. Error[1]	t
Normal	1558.81	172.13	23.12**
Screened	2254.61	381.80	

[1]Standard error was added to the lower value and subtracted from the higher value in each set.

[2]r Correlation coefficient

*Significant at the 5% level

**Significant at the 1% level

TABLE IX

RESULTS AND ANALYSIS OF TENSION PERPENDICULAR SPECIMENS FOR NORMAL AND SCREENED-PARTICLE BOARDS

Strength Values in Pounds Per Square Inch

Normal Board	Screened-Particle Board
242	530
134	563
209	376
202	418
131	270
156	284
133	485
154	489
164	342
137	375
137	318
154	326

Analysis of Variance Results

Source of Variation	Degrees Freedom	Sums of Squares	Mean Squares	F
Total	23	452274		
Between Boards	1	332055	332055	60.77**
Error	22	120219	5464	

**Significant at the 1% level
r Correlation coefficient

TABLE X

RESULTS AND ANALYSIS OF THICKNESS AND DENSITY MEASUREMENTS FROM THREE LOCATIONS

Thickness and Density Values at Three Locations					
Left		Center		Right	
Thickness	Density	Thickness	Density	Thickness	Density
0.638	54.68	0.659	52.85	0.637	60.37
.635	55.63	.652	51.97	.634	61.25
.624	54.32	.637	52.47	.620	60.12
.607	50.33	.612	48.48	.597	54.74
.601	49.60	.610	48.81	.593	54.81
.598	48.79	.606	49.55	.593	54.27
.598	51.89	.603	50.79	.595	60.64
.596	51.99	.605	49.18	.592	59.87
.594	50.74	.601	50.69	.589	58.76
.607	56.71	.620	51.04	.606	61.80
.608	58.39	.622	50.56	.608	61.67
.609	55.25	.623	50.67	.609	63.59
.598	50.55	.610	47.15	.598	57.97
.599	50.84	.612	48.53	.598	57.56
.599	52.34	.609	47.82	.597	59.16
.589	50.20	.598	48.61	.587	56.98
.586	50.38	.595	48.74	.587	56.68
.583	49.33	.592	48.01	.585	56.07
r = 0.645**		r = 0.758**		r = 0.584**	

r Correlation coefficient

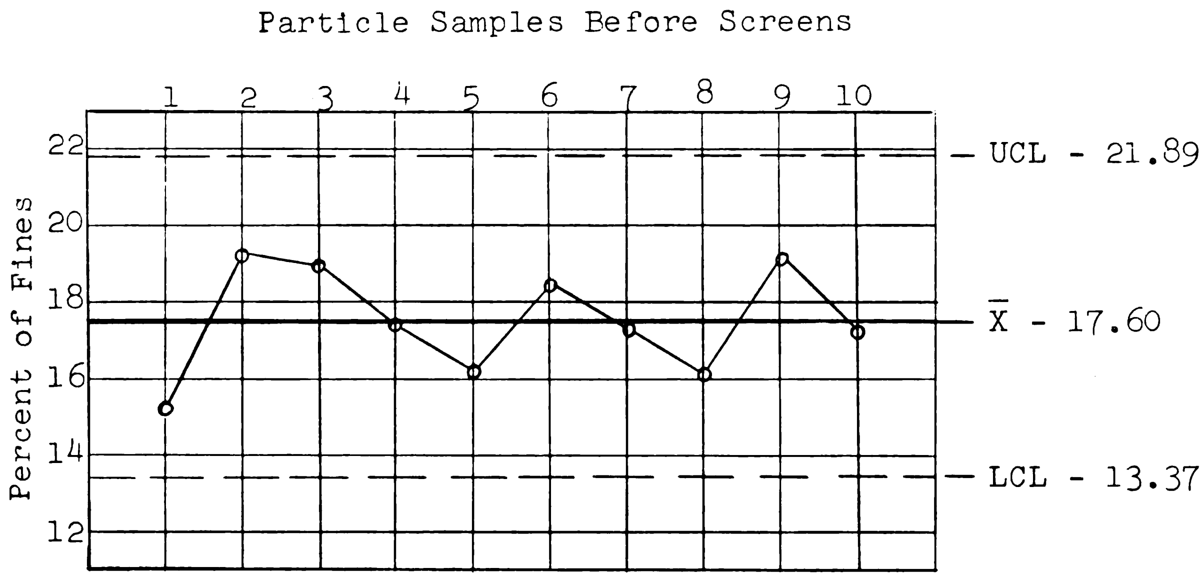
**Significant at the 1% level

TABLE XI

PERCENT OF FINE PARTICLES BEFORE AND AFTER SCREENING WITH COMPUTATIONS FOR $\overline{X}$ CHART

	Percent of Fine Particles	
	Before Screen*	After Screen*
	15.20	17.50
	19.30	16.70
	19.00	15.70
	17.60	21.50
	16.20	22.20
	18.60	18.60
	17.40	23.20
	16.10	15.90
	19.20	17.20
	17.40	18.40
Totals	176.00	186.70
$\overline{X}$	17.60	18.67
x	1.43	2.68
UCL	21.87	26.71
LCL	13.37	10.63

*N is 1 measurement for each value.



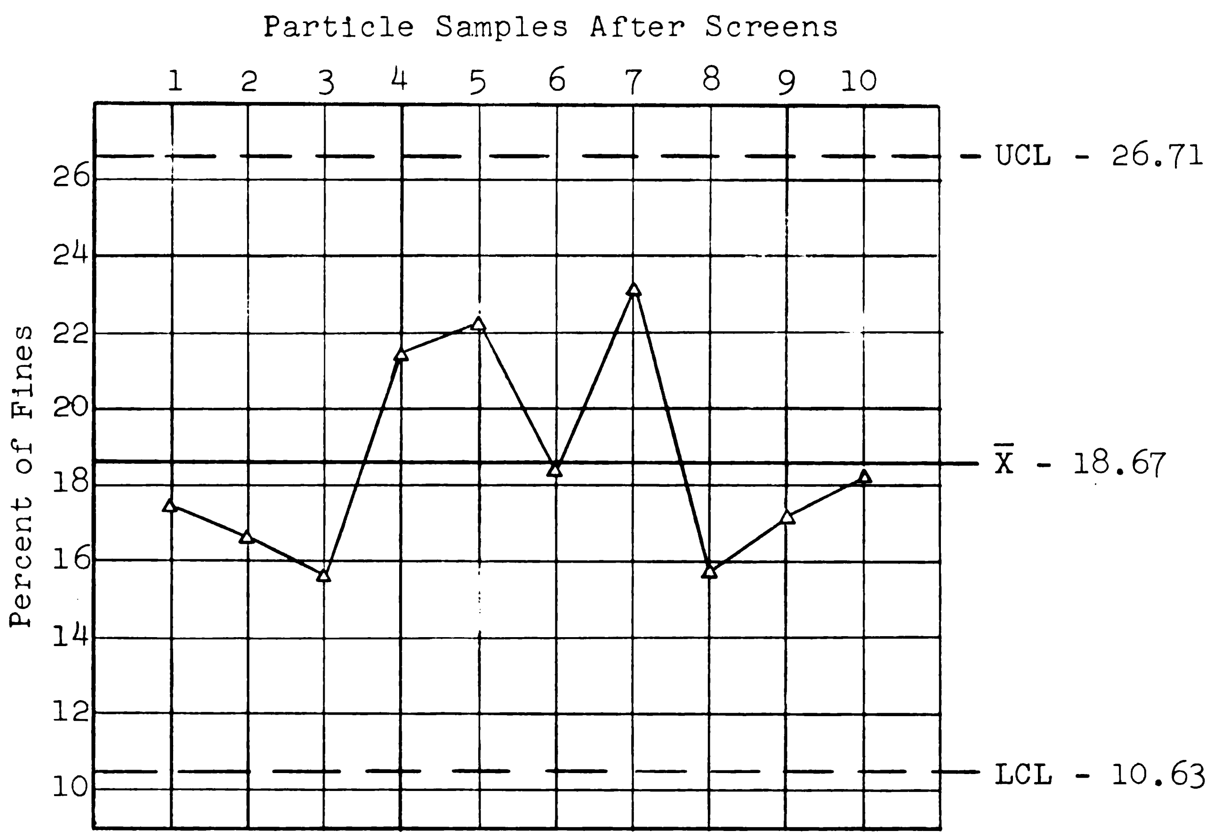


Fig. 9. Control Charts for Percent of Fine Particles Before and After Screens

TABLE XII

THICKNESS MEASUREMENTS WITH COMPUTATIONS FOR $\bar{X}$ AND R CHARTS

Thickness Values With Averages and Ranges

Measurements*				
One	Two	Three	$\bar{X}$	R
0.638	0.659	0.637	0.645	0.022
0.635	0.652	0.634	0.640	0.018
0.624	0.637	0.620	0.627	0.017
.607	.612	.597	.605	.015
.601	.610	.593	.601	.017
.598	.606	.593	.599	.013
.598	.603	.595	.599	.008
.596	.605	.592	.598	.013
.594	.601	.589	.595	.012
.607	.620	.606	.611	.014
.608	.622	.608	.613	.014
.609	.623	.609	.614	.014
.598	.610	.598	.603	.012
.599	.612	.598	.603	.014
.599	.609	.597	.602	.012
.589	.598	.587	.591	.011
.586	.595	.587	.589	.009
0.583	0.592	0.585	0.587	0.009
		Totals =	10.922	0.244

$\bar{\bar{X}} = 0.6067$

$\bar{R} = 0.0135$

$\bar{X}$ control limits

UCL = 0.6205

$\bar{\bar{X}} \pm 0.0138$

LCL = 0.5929

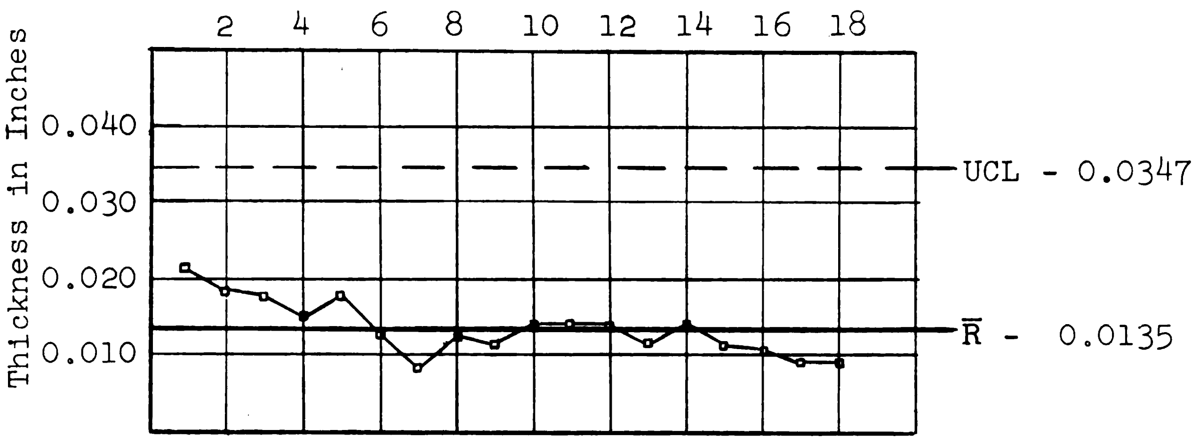
$\bar{R}$ control limits

UCL = 0.0347

$\bar{R} \pm 0.0212$

* Three measurements across board N equal 3.

$\bar{X}$ - Chart for Average Thickness Values[1]



R - Chart for Range in Each Group

Fig. 10. Thickness Control Charts

[1]Average values based on three measurements across the board.

VI. CONCLUSIONS AND RECOMMENDATIONS

Wood Species and Forms

Conclusions.--From sample results of this variable it appears that mixing of species is done. The effects, resulting from species mixtures entering extruded particle board, were not examined.

Recommendations.--L. F. Bornstein(9) states that, "In Chipboards, uniformity of particle size and shape is more important than uniformity of species." It is felt that some fruitful investigation could be performed in this area with primary emphasis placed on factors affecting particle size.

Particle Size

Conclusions.--The analysis of chip samples at three locations along the production line indicated a large amount of fine particles appearing between the drying and screening operations. That the hammer mill, after drying, was producing the excess of small chips is the only possible conclusion to be drawn. No difference between particle sizes before and after screening leads to the conclusion that the lower vibrating screen was inefficient because of the metal covering.

Recommendations.--It would seem that re-design of the chip production process and equipment would help in attaining a more uniform particle size. Two suggestions for reducing the amount of fine particles are: [1] do not hammer mill dry material, [2] remove the metal cover and replace the lower screen with a smaller mesh screen.

Thickness and Density Variation

Conclusions.--Results from the thickness and density studies indicate that variables affecting these two properties should be discussed in one section. Similarity of results and the significant correlation between thickness and density reveal that both properties are affected by corresponding variables.

Conclusions regarding singular factors affecting variable density and thickness between boards cannot be drawn, since a sufficient quantity of data is not available. It is felt that any factor affecting friction or compressibility will, to a certain extent, influence thickness and density.

Limited information is available concerning factors that may affect friction between the chip mass and the platens. Lubricant, resin, and catalyst may be significant variables. Probable factors affecting compressibility may be moisture content, particle size, wood species, and board thickness. Thickness, together with friction, is a determinant of pressure.

Variability of thickness and density values across the boards may also be a result of friction and compressibility as affected by raw material characteristics; however, the unique pattern of variation gives an insight into press characteristics that could be the main source of differences.

Undoubtedly, friction, force, and resultant pressure, as discussed in Chapter II, page 17, have a considerable influence on density and, therefore, thickness. Although no study of force and friction was attempted, it is felt that some inferences regarding thickness and density variations from edge to edge, may be included as possible explanations of the deviations.

Pressure resulting from force and friction is transmitted through the particles into the press. This internal pressure may vary from place to place along the length of the press; however, at any particular location, internal pressure across the press width would be the same for all points. Location of holding devices and press construction may combine to allow this internal pressure to deflect the central portion of the platens outward, thus creating a wider orifice, greater thickness, and lower density of the center.

The study of particles entering the press showed a difference between chips entering the right side of the press and those entering the center. This difference is felt to be small, but it may contribute to the higher densities evidenced along the right edge of the boards.

Recommendations.--Evidence suggests that among all the contributing agents, the press is the controlling variable factor. Because of this conclusion, it is felt that a detailed study of the press and its basic principles should be undertaken.

The Effect of Particle Size on Strength

Conclusions.--The comparative tests, between strength values of specimens from boards composed of normal particles and those composed of particles from which fines had been removed, illustrate that at 7 percent resin content, a stronger extruded particle board can be manufactured by excluding most of the fine chips.

In normal boards, the lack of a correlation between density and strength values, parallel to the extrusion direction, intimates that small particles do effect the bending characteristics of extruded board.

Recommendations.--It has been pointed out that strength may vary with changes in particle size. Strength may also vary with resin content. Because of this fact, future investigations of the related variables may be directed toward determination of maximum and minimum resin content for a given particle size and type, or vice-versa.

Process Control

Conclusions.--Three steps are necessary in the derivation and employment of a useable control system. First of these is to select the variable(s) to be measured. For this process, investigation and statistical analysis were found useful in making the decision. Results obtained from the study revealed that particle size and board thickness should be controlled.

After the representative factors have been chosen, measurements must be taken at specific time intervals and expressed in a form suitable for analysis. The most common representation of variable factors is by means of a control chart. Control limits[1] are normally set on the basis of probability. The charts for particle size and board thickness on pages 57 and 59 were constructed according to methods described by A. S. Duncan (10).

Analysis of the charted measurements is the final key to successful quality control. Any point falling beyond the specified limits is out of control. Some

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[1]Control methods and the derivation of limits can be found in most texts concerning quality control and in some statistic books.

attributable factor or factors, among the affecting variables, can usually be indicated as a cause for variation, if the affecting variables are known and recorded in the same time sequence as the controlled variable. The cause can be remedied before much unacceptable product is made.

In many cases, trends toward an out of control situation can be recognized and the affecting variable(s) corrected without relinquishing control. Plotted points on dual charts for grouped data may not necessarily follow the same patterns. This is illustrated by the thickness control charts on page 59. The average chart is a measure of the over-all variability for the total product, whereas the range chart is a measure of the variance between values in each group.

Due to the fact that only a limited amount of information could be collected in the apportioned time, a sufficient quantity of data, necessary for developing an accurate control system, was not obtained. It is felt that use of the available data does illustrate a possible control system for the process.

Recommendations.--The illustrated plan may not be the best one attainable; however, until more significant information can be acquired, this method should provide a reasonable degree of control. Variables affecting particle size are wood species, moisture content, and the particle production machinery.

Basic press principles and their effect on thickness can not be disregarded in the analysis of a thickness control chart. It would seem that not much can be done to control variation from edge to edge; however, results of the study[2] indicate that a control chart should be devised for each press setting. Factors that should be recorded as variables affecting thickness would be; particle moisture content, resin content, lubricant, catalyst, and possibly press temperature.

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[2]Results from the study indicated the average range of 0.600 inch boards was greater than that for 0.700 inch boards.

APPENDIX

TESTING PROCEDURES

Flexural Bending Tests

This test was conducted in accordance with specifications set up by the National Woodwork Manufacturers Association (7). Six test specimens were cut from each board. Three were taken with the length of the specimen parallel to the direction of extrusion and three with the length perpendicular to the extrusion direction. Dimensions of each specimen were: a length equal to twenty-four times the nominal thickness plus two inches, a width of three inches plus or minus 0.03 percent, and the actual board thickness.

Micrometer measurements at three points along the length of each specimen, were used to determine average width and thickness.

Specimens were tested on a Baldwin Emery Universal 50,000 pound testing machine. A picture of the test method appears in Figure 11.

Testing speed was controlled by the variable drive mechanism of the testing machine. The appropriate speed was obtained from the following formula (7):

$$N = \frac{zL^2}{6d} \tag{A-1}$$

Where:
N Rate of moving head, in inches per minute
z Unit rate of fiber strain, in inches per inch of outer fiber length per minute (0.005)
L Span in inches
d Thickness of specimen in inches

A supplemental variable range load cell was used to magnify the small loads required to break the specimens. Maximum load for each specimen was recorded by a static needle on the range scale. Values were recorded from the scale. Deflection curves, plotted by the stress-strain recorder of the testing machine, were used to determine stress at proportional limit.

Modulus of elasticity and rupture were calculated, for each specimen, using the following formulae (7):

$$\text{(A-2)} \quad MOE = \frac{Pl\ L^3}{4\ b\ d^3\ y}$$

$$\text{(A-3)} \quad MOR = \frac{3\ p\ l}{2\ b\ d^2}$$

Where:

L Span length in inches
Pl Load at proportional limit in pounds
d Average thickness of specimen in inches
b Average width of specimen in inches
y Center deflection at proportional limit lead, in inches
p Maximum load in pounds

A two inch section was cut from each specimen immediately following the test. The sections were weighed, dried in an oven at a temperature above 100 degrees centigrade, and reweighed. Moisture content at time of test was determined from the normal formula shown below:

$$\text{(A-4)} \quad MC \quad \frac{\text{green weight} - \text{oven dry weight}}{\text{oven dry weight}}$$

Each section was measured to determine the oven-dry volume. This volume was used along with the oven-dry weight to compute the oven-dry density, in pounds per cubic foot, for each specimen. The following formula was used(7):

$$\text{(A-5)} \quad \text{Specific weight} \quad \frac{\text{dry weight in grams x 3.81}}{\text{dry volume}}$$

Tension Perpendicular to the Surface

This test was also performed in accordance with recommendations of the National Woodwork Manufacturers Association (7) on three samples selected at random from each board. The test was designed to examine cohesion of particles in the direction perpendicular to the plane of the board.

A two inch square section of the particle board was glued between two blocks of maple, which were two inches square by one and one-half inches thick. A cold setting urea-formaldehyde resin was used to establish the bond between the blocks and the particle board. Pressure was applied during curing by use of clamps. After curing, a hole was drilled through the center of each maple block, so that the specimens could be fixed in a jig for testing.

Each particle board center was measured to determine surface area and was then tested.

A picture of the test specimen used and the method of test appears in Figure 12. The jigs holding the specimen were set into the upper and lower platens of a Baldwin Emery Universal testing machine. Stresses other than pure tension were effectively eliminated by placing the holding devices in such a manner that a double universal joint was created.

Testing speed was maintained by the variable drive mechanism of the testing machine at 0.08 inches per inch of particle board thickness per minute.

Maximum loads were recorded by the static needle of the range scale. The values were recorded and then reduced to pounds per square inch by using the predetermined surface area. Percentage of board failure was also estimated for each specimen.

Density Tests

Approximately one inch was cut from the edge of each board and density samples were selected from the left, center, and right locations. Specimen size was slightly under four inches square. Length, width, and thickness measurements were taken with a micrometer. The average length, width, and thickness were calculated. The specimens were then weighed and the density in pounds per cubic foot was derived from formula (A-5).

Fractional Division of Particle Samples

A series of five, interlocking, graduated screens was used to divide chip samples into fractions. A picture of these screens and the mesh sizes appear in Figure 13.

A particle sample was weighed on a triple-beam balance and its weight recorded to the nearest 0.01 gram. The sample was then placed on the uppermost screen and covered. The screens were then agitated until all chips smaller than one screen mesh, but larger than the next lower mesh, had been separated into five groups. Time of agitation was approximately two minutes.

The fractions were weighed and the percentage of each fraction determined. Since some of the particles passed through the smallest mesh, it was found necessary to use a sixth fraction. The weight of lost chips was calculated by subtracting the total weight of the five known fractions from the sample weight. Sample number and fractions were recorded for future analysis.

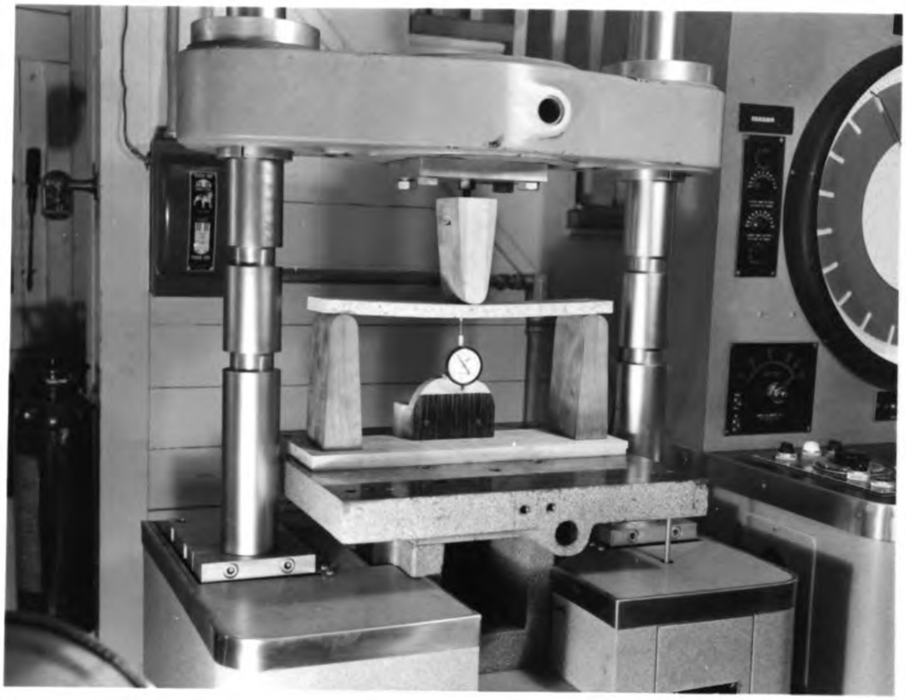

Fig. 11. Flexural Bending Test Method

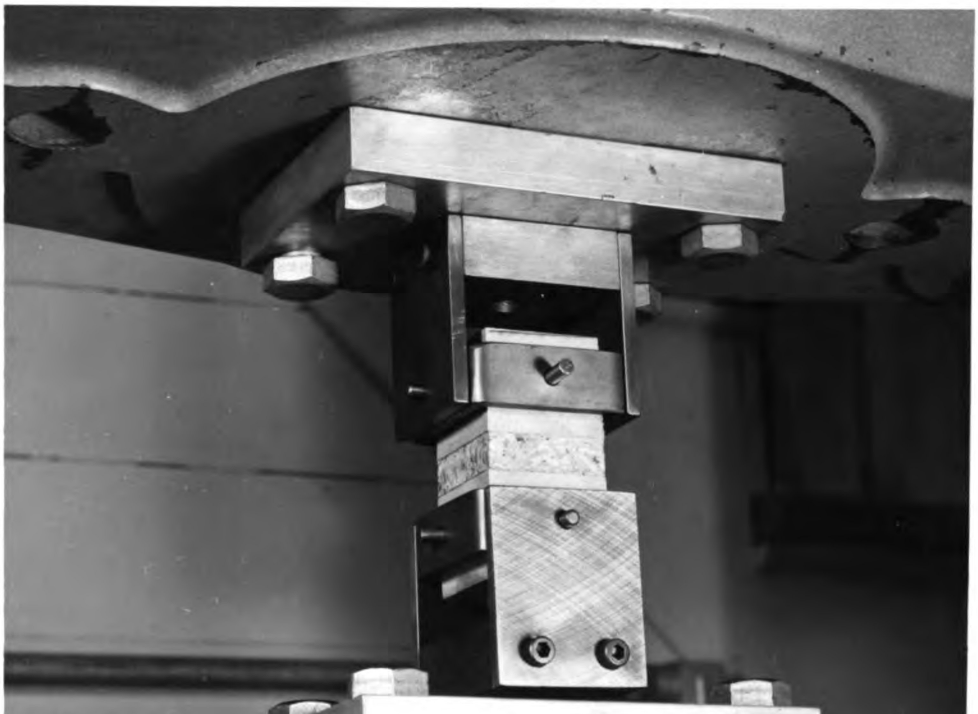

Fig. 12. Tension Perpendicular to the Surface Test Method

Fig. 13. Frationating Screens and Mesh Sizes

In Inches: a -- 0.185
b -- 0.0932
c -- 0.0469
d -- 0.0232
e -- 0.0117

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