THE EFFECT OF REFINING TIME AND HOT-PRESSING CONDITIONS ON THE PROPERTIES OF LODGEPOLE PINE FIBERBOARD

by

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It is the sincere hope of the author that this study will contribute some information on the utilization of wood waste and, in so doing, fulfill the expectations of the Mary J. L. McDonald Fellowship to which the author is greatly indebted for monetary assistance.

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THE EFFECT OF REFINING TIME AND HOT-PRESSING CONDITIONS ON THE PROPERTIES OF LODGEPOLE PINE FIBERBOARD

INTRODUCTION

As an outgrowth of the work done by the Oregon Forest Products Laboratory in cooperation with Mr. Ralph Chapman in the development of a resin impregnated fiberboard from Douglas fir slabwood, a study was instigated to determine the effect of the variables involved in the major operations on the properties of fiberboard made from raw wood fiber without the addition of sizing, resins or other binders. It was hoped that such a study might point the way to the development of a better product at a lower cost through a better understanding of the factors involved.

At the time this study was instigated considerable interest was focused on the development of a wood fiber industry in central Oregon, and especially with regards to the utilization of lodgepole pine which constitutes a large portion of the forested area of that region. As a result of this interest, and recognizing the need for the development of methods for the utilization of so called "secondary species" of Oregon, lodgepole pine was used as the source of fiber for this study.

Previous work at the laboratory had indicated that the major operations which should first be considered

were refining and pressing. The principle factor in the former is refining time, and the factors in the latter are pressure, pressing time - temperature, and weight of fiber used. The effect of bark was also studied to determine if complete utilization of the tree were possible. Later studies may show that such factors as pH control during refining and the method of preforming may be at least as important as the factors considered in this study.

The evaluation of the factors was based on their effect on the following properties of the finished fiberboard: (1) Strength, (2) Per cent swelling and absorption on 24 hour water immersion, (3) Density, and (4) Color. Since this study was exploratory rather than for the development of a specific product, no attempt was made to set a standard for comparison, but rather to point out which factors affect what property and to what extent.

LODGEPOLE PINE

NOMENCLATURE

Lodgepole pine as it is known in Oregon consists of two recognized forms. They are the coast form, Pinus contorta Dougl.(11, p. 178)(14, p. 108), and the mountain form, Pinus contorta var latifolia Engelm(11, p. 178). Both species are very similar in appearance, structure, and chemical composition. Although the species used in this report was Pinus contorta var latifolia in so far as the nature of this report is concerned both may well be included under the common name of ladgepole pine or Jack pine.

There is, however, considerable confusion in the literature as to the nomenclature of the various forms of this species. Some taxonomists recognize the mountain form of lodgepole pine as a distinct species, Pinus murrayana Grev. Balf(11, p. 178) while others are prone to recognize the lodgepole pine of medium altitudes as a separate variety, Pinus contorta var murrayana Balf. Englem.(21, p. 59). Harlow and Harrar(14, p. 108-109), recognizing that lodgepole pine does have a great variation in its morphological characteristics, contend that there are no reliable differences upon which such separations can be based. Range restrictions, however, offer sufficient

contrast for the separation of the coast and mountain forms.

DESCRIPTION

Lodgepole pine is a comparatively small tree, varying in height from 30 to 50 feet and up to 12 inches in diameter along the coast to 80-150 feet in height and up to three feet in diameter in the Rocky Mountains. Its bole is slender, cylindrical and characterized by a thin, hard, multifissured, reddish-brown to black outer bark that from a distance appears to be made up of small irregular flakes. The crown is narrow and open with short yellow-green to dark green needles, two in a fasicle. The cones are ovoid in shape, asymmetric at the base and from 3/4" to 2" long. They may remain closed for years after maturing and open following fires which also develop favorable seed bed conditions, to produce the nearly pure, dense, even aged stands in which it is usually found. It may, however, form mixed stands with other species, such as ponderosa pine, Douglas fir, alpine fir, and Jeffrey pine.

Often as a result of fire this species will form such dense stands that stagnation results, and the trees remain small and of very uniform diameter. It is normally a slow growing species and matures in 140 to 200 years.

RANGE

Pinus contorta is restricted to a comparatively narrow belt along the Pacific coast in Alaska, British Columbia, Washington, Oregon, and northern California.

Pinus contorta var latifolia extends from the edge of the coast regions eastward into the Black Hills of South Dakota(13, p. 70) and from the Yukon river through the Cascades, Sierra Nevadas and San Jucinto mountains to the northern parts of lower California, throughout the Rocky Mountain Region to northern New Mexico, and along the intermediate ranges into Washington and Oregon. It ranges in altitude from less than 1,000 feet to 11,500 feet, with commercial limits of 3,000 to 11,000 feet.

DISTRIBUTION IN OREGON

Both forms are found in Oregon though Pinus contorta is restricted to a very narrow belt along the coast. One or both forms are found in all but ten Oregon counties, with the bulk of the lodgepole pine area consisting of Pinus contorta var latifolia which extends diagonally from the southwest corner to the northeast corner of the state. The total area in Oregon is estimated to be 1,857,000 acres(Table 1, p. 7). Of this total acreage 59.7 thousand acres or 3 per cent is classed as sawtimber area. The remaining 97 per cent consists of trees less than 12

inches in diameter. Although a portion of this represents potential sawtimber, a great portion represents forest land from which a timber crop can never be realized and for which new uses should be developed. The area and volume by county is shown in Table 1, page 7.

Over 70 per cent of the sawtimber area, and 71 per cent of the sawtimber volume is found in Deschutes, Klamath and Lake counties. Most of the remaining sawtimber is found in the Blue Mountain region of northeastern Oregon. These same three counties contain 64 per cent of the total lodgepole pine area. Lodgepole pine represents 13 per cent of the total forest land area of Oregon which ie estimated at 14,085,300 acres(18, p. 57).

Table 2, page 8 shows the distribution of the total area and total volume of lodgepole pine by ownership classes. Approximately 87 per cent of the volume and 73 per cent of the lodgepole pine area is found on National Forest land, nearly all of which is available for cutting.

USES, PRODUCTION, SUPPLY

Lodgepole pine is used chiefly for ties, mine timbers, and small poles. Its use for lumber and paper pulp is steadily increasing. Considerable quantities are used for fuelwood and posts. Since this species must be treated with preservatives for most of its uses a fair idea of

TABLE 1

AREA AND VOLUME OF LODGEPOLE PINE IN OREGON BY COUNTY(19)

County	Area in Acres	Vol. M Bd. Ft.	Survey
Baker	32,030	32,439	1937
Benton	0	0	1941
Clackamas	18,219	2,555	1933
Clatsop	105	0	1933
Columbia	0	0	1938
Coos	9,140	0	1940
Crook	2,930	5,678	1937
Curry	Not Listed	0	1933
Deschutes	340,125	115,060	1936
Douglas	66,004	4,730	1933
Gilliam	Non-Forested	-------	----
Grant	131,560	31,302	1937
Harvey	140	0	1936
Hood River	843	3,903	1933
Jackson	6,168	860	1933
Jefferson	23,170	6,177	1935
Josephine	623	0	1933
Klamath	695,395	234,214	1934
Lake	159,400	167,157	1935
Lane	74,315	22,211	1942
Lincoln	5,335	48	1944
Linn	44,631	2,679	1933
Malheur	Non-Forested	-------	----
Marion	8,373	0	1933
Morrow	16,265	3,505	1937
Multnomah	0	0	1932
Polk	0	0	1942
Sherman	Non-Forested	-------	----
Tillamook	1,795	0	1942
Umatilla	48,800	15,418	1937
Union	111,655	32,564	1937
Wallowa	46,050	24,824	1937
Wasco	11,420	21,744	1934
Washington	0	0	1940
Wheeler	4,600	1,136	1937
Yamhill	0	0	1942
Total	1, 859,101	718,711	

TABLE 2

AREA AND VOLUME OF LODGEPOLE PINE IN OREGON BY OWNERSHIP CLASSES(19)

Ownership Class	Area in Acres	Per Cent of Total	Vol. M Bd. Ft.	Per Cent of Total
Private	246,135	13.22	80,879	11.33
State(available and reserve)	2,500	0.13	1,451	0.20
County	9,545	0.51	787	0.07
Indian, Tribal	184,095	9.90	6,464	0.90
Public Domain	58,475	3.15	2,749	0.38
National Forest				
Available	1,226,987		558,107	77.59
Reserve	128,947		67,950	9.50
Total	1,355,933	72.94	626,057	87.09
Others	2,697	0.15	474	0.03
Total	1,859,631	100.00	718,711	100.00

the amounts utilized may be obtained from data on treated material. It is estimated in the Wood Preserving News, Sept. 1946(24, p. 81) that 1,028,675 cross ties, 128,424 poles, and 60,793 board feet of switch ties were treated in 1945. Assuming 35 board feet per cross tie and 100 board feet per pole this represents approximately 48,807,000 board feet of lodgepole pine.

The production of lodgepole pine lumber in Oregon for the past 5 years is given below(20).

Year	M Feet
1940	853
1941	2,159
1942	1,063
1943	1,200
1944	5,477

Betts(9, p. 3-4) estimates the total annual cut of lodgepole pine for the ten year period from 1930 to 1940 to exceed 100,000,000 board feet, and based on his estimates the production may be divided as follows,

Product	Million Board Feet
Lumber	59
Ties	40
Poles	5
Mine Timbers	10
	Total 114 million board ft.

The total supply of lodgepole pine in the United States is estimated to be 38.6 billion board feet(10) of which one-third is located in the Pacific Northwest. The total volume in Oregon as given in Table 2, page 8 is estimated at 718.7 million board feet.

PROPERTIES OF WOOD

MACROSCOPIC FEATURES

Lodgepole pine sapwood is nearly white with a slight yellowish tinge, and it is very often indistinguishable from the nearly white to pale yellow-brown heartwood. The freshly cut wood has a characteristic pleasant, resinous odor. The wood is usually straight grained, has a fine uniform texture with narrow but distinct growth rings, and contains many small, hard, black knots. Both longitudinal and radial resin ducts are present though not readily noticeable. It is similar to ponderosa pine in general structure and particularly in that both have small dimples on the split tangential surface of the wood. However, the heartwood of ponderosa pine is distinctly darker, the longitudinal resin ducts are more distinct, and the wood is more yellowish.

MICROSCOPIC FEATURES

The growth rings are distinct with fairly abrupt

transition from springwood to summerwood. The early wood tracheids are thin walled and from 30 to 50 microns in diameter. The late wood tracheids are thick walled. Spiral thickenings are absent. The radial walls of the springwood tracheids are quite heavily pitted with large single and occassional double bordered pits. The tangential walls are not pitted, and tangential pitting is lacking in the last few rows of late wood tracheids. Both uniseriate and fusiform rays are present. Uniseriate rays are from 2 to 12 cells high. The fusiform rays are well scattered and each contains one transverse resin duct. Ray tracheids are present as marginal rows and the walls are irregularly thickened varying from dentate to reticulate. The ray paenchyma cells are thin walled with 1 to 7(2-4 most frequent) small irregular pits per crossfield. Both vertical and transverse resin canals are present and frequently are occluded withtylosoids. The epithelial cells are thin walled. The vertical resin ducts have an average diameter of 90 microns, the transverse resin ducts 20-70 microns. Longitudinal parenchyma strands are absent.

STRENGTH

As shown by Table 3, page 12 the strength values of lodgepole pine and ponderosa pine are very similar, and

TABLE 3

STRENGTH PROPERTIES OF LODGEPOLE PINE WOOD AS COMPARED TO PONDEROSA PINE AND DOUGLAS FIR (7) (12)

	L.P.	P.P.	D.F.
Specific Gravity(12% MC)	.41	.40	.48
Static Bending(12% MC)			
Fiber Stress at Elastic Limit(p.s.i.)	6,700	6,300	8,100
Modulus of Rupture(p.s.i.)	9,400	9,200	11,700
Modulus of Elasticity (1000 p.s.i.)	1,340	1,260	1,920
Work to Proportional Limit(Inch lb. 3/4 cu. Inch)	1.97	1.85	1.96
Work to Maximum Load (Inch lb./cu. Inch)	6.8	6.6	8.6
Impact Bending			
Fiber Stress at Elastic Limit(p.s.i.)	9,600	9,800	12,700
Heighth of Drop to Cause Complete Failure (Inch)	20	17	30
Compression Perpendicular to Grain			
Fiber Stress at Elastic Limit(p.s.i.)	750	740	910
Shear Parallel to Grain			
Maximum Shear Strength p.s.i.	880	1,160	1,140
Hardness(Pounds)			
End	530	550	760
Side	480	450	670
Tensile Strength Perpendicular to Grain p.s.i.			
Cleavage Strength(Lb./Inch of Width)			
Radial	142	162	139
Tangential	140	187	127
Shrinkage Green to Oven Dry			
Volume %	11.4	9.7	12.1
Radial%	4.5	3.9	5.0
Tangential %	6.7	6.3	7.8

both are considerably weaker than Douglas fir in nearly all respects except cleavage. Lodgepole pine is softer and is lower in shear parallel to grain than the other two species. It is slightly stronger than ponderosa pine in compression perpendicular to grain and static bending.

CHEMICAL ANALYSIS

A comparison of the chemical analyses of the coast and mountain forms of lodgepole pine are shown in Table 4, page 14 and of lodgepole pine, ponderosa pine, and Douglas fir in Table 5, page 15. The two forms of lodgepole pine are chemically very similar though, as indicated by these analyses, the coast form tends to be higher in total extractives and lower in holocellulose. The per cent holocellulose as determined for the coast form is questionable for the sum of the lignin and holocellulose is only 87.17 per cent where as it should be in the neighborhood of 96 to 100 per cent.

Lodgepole pine is much lower than both ponderosa pine and Douglas fir in ash content and total extractives but higher in total pentosan and pentosan in cellulose. The cellulose and lignin content of lodgepole pine and ponderosa pine are nearly identical but both are about 4 per cent lower than Douglas fir in cellulose content.

TABLE 4

CHEMICAL ANALYSIS OF WOOD

Constituent	Pinus contorta var latifolia(8)* per cent	Pinus contorta (16, p. 5)*
Lignin	25.9	26.21
Holocellulose	71.6	60.96
Cellulose(Cross and Bevan)	57.6	56.47
Alpha Cellulose	42.7	-----
Pentosans: Total	10.9	-----
Pentosans in Cellulose	9.2	-----
Solubility in:		
Alcohol Benzene	2.8	4.14
Ether	1.3	0.91
1% NaOH	11.6	14.37
10% NaOH	----	20.84
Water, Cold	----	2.65
Water, Hot	3.6	3.36
Ash	0.2	0.24

*Source of Wood

Pinus contorta var latifolia - Granite County, Montana

Pinus contorta - Newport, Oregon

TABLE 5

COMPARISON OF THE CHEMICAL ANALYSES OF LODGEPOLE PINE, PONDEROSA PINE, AND DOUGLAS FIR

Constituent Per Cent	Pinus contorta var latifolia (8)	Pinus ponderosa (26, p. 658)	Pseudotsuga taxifolia (26, p. 658)
Ash	0.2	0.46	0.38
Solubility in			
Cold Water	2.65	4.09	3.54
Hot Water	3.6	5.05	6.50
Ether	1.3	8.52	1.02
1% NaOH	11.6	20.30	16.11
Acetic acid	----	1.09	1.04
Methoxyl	----	4.49	4.95
Pentosan	10.9	7.35	6.02
Methyl Pentosan	----	1.62	4.41
Cellulose(Cross and Bevan)	57.6	57.41	61.47
Lignin	25.9	26.65	-----
Pentosans in Cross and Bevan Cellulose	9.2	6.82	5.34

FIBERBOARD

DEFINITION

Fiberboard in general refers to any board made by compacting fibers, as of wood, straw, cornstalk or sugar cane, into a stiff sheet. Any attempt to further define fiberboard must be based in terms of the finished product.

Fiberboard products made from wood fall roughly into three classes. They are (1) Structural, (2) Semi-structural, and (3) Non-structural. This classification is also a measure of the board's density, strength, resin content and moisture resistance, all of which are greatest in class 1 and lowest in class 3. The structural boards are those used primarily to strengthen the products in which they are used and which form an integral part of the structure. However, in some instances where moisture resistance is required, such as table tops, strength may be of secondary consideration.

Semi-structural boards are those used mainly as a base for some other type of surface coating but which add some rigidity to the structure. These include primarily the wall boards. The non-structural class includes the insulating boards and acousticle tiles which are fastened to the structure for a specific purpose and which do not

add to its strength.

Fiberboard as referred to in this paper is a board made by consolidating wet mechanical wood fiber, without sizing, resin, or other binders, under heat and pressure to form a sheet one-tenth to two-tenths of an inch in thickness with a density from 0.7 to 1.0. The product is a semi-structural board.

THE MANUFACTURE OF FIBERBOARD

The manufacture of fiberboard involves four basic operations. They are (1) the reduction of wood to fiber, (2) the preforming of the wet fiber, (3) consolidation of the preforms under heat and pressure, and (4) the conditioning of the final product for use. Sizing and resins are usually added to impart both stability and added strength to the board. They may be incorporated in the fiber "slurry" prior to the preforming operation or by surface coating of the board directly after the pressing operation.

The reduction of wood to fiber may be accomplished by (1) chemical means as in the pulp and paper industry, (2) by so called semi-chemical means which involves a short cook in sodium hydroxide or sodium solfite to soften the chips followed by a mild explosion of the chips to fibers, and then a refining operation, (3) by the explosion

of chips under steam pressure as in the Masonite process, and (4) by purely mechanical means. The mechanical methods include grinding as in the production of groundwood pulp, attrition grinding of steam softened chips between discs as in the Bauer, Sprout Waldron, and Asplund processes, and defiberization of slab wood to fiber aggregates by the Allis Chalmers(MacMillen) process.

The fiber may be further refined to produce a more complete separation of the individual fibers and thus improve the bonding characteristics of the fiber. This refining operation may be accomplished by numerous methods which fall roughly into five classifications (25, p. 4). They are the roll and bed plate, the impact, the hammer, or rod mill, the plate or disc, and the conical plug and shell type.

The fiber is then formed into a sheet which may be partially consolidated to remove some of the water. The preforming operation may be accomplished on a modified Fourdrinier, on a cylindrical lap machine, or on a stationary screen from which the free water may be removed by suction or gravity. The purpose of the preforming operation is three fold in that it brings the fibers in contact at all angles, a portion of the water is removed, and the fiber is in the desired form for the pressing operation.

The wet sheets are usually pressed in multi-platen

steam heated presses at approximately 350°F. and at a pressure of 300 pounds per square inch. The pressure in some instances may exceed 1000 pounds per square inch. In this operation the fiber is consolidated to the desired density or thickness, the fiber bonding takes place with the elimination of the water, any resins that may have been incorporated are set and the board emerges in its final form at a very low moisture content. The pressure serves two purposes in that it aids in the removal of the water and brings the fibers and fiber bundles into close contact so that as the water is evaporated by heat a better bonding of the fibers takes place.

To help prevent warping and change in size of the boards they are conditioned to a moisture content comparable to the conditions existing where the boards are to be used. This varies from 8 - 12 per cent in the United States.

THE RELATION OF FIBER BONDING TO WOOD STRUCTURE

THE ANATOMY OF CONIFEROUS WOOD

Well over 90 per cent of the total cell volume of coniferous wood is composed of elongated imperforate cells called tracheids which are oriented very nearly parallel to the axis of the stem and laid down in more or less concentric layers. Distributed throughout this matrix are radial lines of parenchymous cells usually one cell wide and of varying length and depth. These radially arranged groups of cells are called rays and are oriented with their longitudinal axis at right angles to the tracheids. In addition to these two main cell structures some woods contain occassional single longitudinal parenchyma strands oriented parallel to the tracheids and of indefinite length. Some woods are also characterized by small openings in the wood matrix, the inner surface of which is composed of short, flat parenchymous cells known as epethelial cells. These openings are called resin ducts and may extend both longitudinally and radially. The radial resin ducts are considerably smaller than the longitudinal ducts and are contained in fusiform rays.

The cells are formed from the cambrial layer between the wood and the inner bark during the growing season. Early in the growing period the cells laid down are large, thin-walled and tend to be hexagonal in cross section.

As the growing period proceeds the cells may gradually decrease in size or this transition may be abrupt. In either case the cells formed are smaller, have thicker walls and are rectangular in shape being radially shortened or compressed but tending to maintain their tangential dimension. It is this characteristic growth that gives rise to the annual rings in woody stems.

The chief function of rays is the storage of food that has been synthesized in the leaves and transported down the phloem of the inner bark and thence into the rays which extend into the inner bark. The average ray volume for coniferous wood was found by Myer(17, p. 337-351) to be 7.8 per cent. Except for the intercellular spaces(resin ducts) the remaining volume is composed entirely of tracheids, and it is this structure which largely determines the characteristics and properties of the wood.

The tracheids vary in length from 1 to 5 mm. and from .02 to .05 mm. in diameter. They are approximately one hundred times as long as they are wide, roughly circular in shape, and pointed at both ends. Their function is two fold in that they give strength to the stem and aid in the conduction of nutrients in water solution to the crown. To aid in this conduction the radial walls have characteristic thin spots called pits which are more numerous towards the ends and especially in the areas where the tangentially flattened walls of adjacent cells

overlap, or where they are in contact with rays. The pits between tracheids are bordered whereas those between tracheids and ray cells consist of a semi-bordered pit pair.

CELL WALL STRUCTURE AND COMPOSITION

The cell wall structure of the tracheids has received considerable study because it is the composition and structure of this wall upon which the bonding and strength of paper and fiberboard is based. Essentially, the cell wall is composed of two layers, the outer continous primary wall and the inner secondary wall. Between the primary walls of adjacent cells is a layer of cementing material, largely lignin, which is known as the middle lamella. Because of the intimate relationship between this middle lamella and the primary walls of the two adjacent cells the three structures are referred to as the compound middle lamella.

The primary wall is extremely thin in comparison to the thick secondary wall, and quite heavily impregnated with lignin. Bailey(3, p. 40) contends that it is composed largely of cellulose, of true pectic substances, and that it may contain some hemicelluloses, whereas Clark (6, p. 385) contends that it is not true cellulose because it does not dissolve in cellulose solvents nor is it attacked by Cellulomonas liquata. Anderson and Kerr

(1, p. 49) in their study of the development of cotton hairs have shown that the primary wall of cotton does contain cellulose but that the presence of this cellulose may be obscured by encrusting pectic substances. The same condition undoubtedly occurs in the primary wall of woody cells due to the impregnation of that wall by lignin and, in addition, it is entirely possible that in this primary wall a definite lignin-cellulose bond may exist.

The thick secondary wall as described by Bailey (3, p. 40) is composed of cellulose, lignin, hemicellulose, little if any pectic substances, is entirely anisotropic, and is more or less conspicuously laminated. Studies under polarized light have shown it to be composed of a thin outer and a thin inner layer with a higher fibril angle, and a thick central layer of low fibrillar angle. By the treatment of delignified wood fibers with swelling and shrinking reagents(phosphoric acid and alcohol) Ritter(23, p. 943-4) found the fibers to be composed of several layers. These layers in turn were separated into threadlike fibrils which were more or less spirally arranged about the fiber. In the outer layer(primary wall) the fibrils extended at approximately right angles to the fiber axis and in the remaining layers(secondary wall) the fibrils varied from zero to thirty degrees to the fiber axis.

Bailey(3, p. 46-47), from the observations of minute checks on the fiber walls and cavities produced by fungi in the walls, and by depositing iodine crystals within the fiber structure was able to show and to measure the angle at which the fibrils were oriented in the walls of the fiber.

When wood is treated with 72 per cent sulfuric acid to remove cellulose or is chlorinated and extracted with ethanol-amine in ethyl alcohol to remove lignin, a definite structural pattern remains. A similar effect is noted when wood is attacked by the so-called brown rots which attack the cellulose and leave the lignin, or by the white rots which destroy the lignin and leave the cellulose. This, in addition to studies of fiber structure under polarized light, has led Bailey(3, p. 43) to conceive of the primary and secondary walls of fibers as being composed of a porous but firmly coherent matrix of anisotropic cellulose, whose finer structural details grade down to the limits of microscopic visibility or less, and within which lignin and other noncellulosic constituents may be deposited resulting in two continuous, inter-penetrating systems.

The present concept of fiber structure is then based primarily on cellulose. It conceives of an outer wall heavily impregnated with lignin and in which the fibrils

are oriented very nearly perpendicular to the cell axis; of a secondary wall composed largely of cellulose which is differentiated into three layers, the inner and outer of higher fibrillar angle than the thicker central layer in which the fibrils are nearly parallel to the cell axis; of fibers cemented together by a substance which is largely lignin; of a porous structure throughout consisting of two inter-penetrating systems of cellulose and lignin plus other noncellulosic materials.

At present the structure of lignin is not understood, but it is known that lignin can be activated or made to flow and then rebonded under proper conditions of temperature and pressure. The properties of Masonite products are thought to be due partly to the activation of the lignin in the "gun" when it undergoes a hydrolytic action, and then to its rebonding during the pressing operation.

The structure of cellulose on the other hand has been quite definitely established. Its sole constituent is glucose. The individual glucose molecules are in pyranose groups joined by beta linkage. The structural unit is thought to be cellobiose which consists of two glucopyranose rings joined through an oxygen linkage. The Cellobiose units are in turn arranged into long chain molecules. A definite bundle of these long chain molecules is called a micelle. These micelles are thought to

be held together by lateral secondary valence forces to form crystallites which give rise to the crystalline pattern of cellulose. The crystallites of cellulose are comparable to the fibrils in the cell walls of the fibers and it is on this concept of the structure of wood that the theories of fiber bonding are based.

THE NATURE OF FIBER BONDING

The investigations of fiber bonding have dealt almost entirely with chemical wood pulps in which the fibers have been delignified and only cellulose with a portion of the other carbohydrate fractions remains. Since in this study the fibers are still highly lignified and have their original chemical composition except, perhaps, for the loss of some water solubles, the two types of fiber are not comparable. However, the theories that have been advanced apply to all cellulosic fibers though differences in the bonding characteristics will exist due to the presence of other substances. Bailey(2, p. 1276) contends that the extensive knowledge of pressing, drying, calendering, and sizing of paper should apply with considerable force to board pressing since the adhesive force appears to be of the same kind and source.

When cellulose sheets are preformed from water, pressed and dried, a product is formed which has good strength properties. However, when cellulose is

deposited from alcohol, benzene, and other liquids, or when other fibrous material such as hair, silk, or asbestos are preformed from water, pressed and dried, only a fibrous mass results with very low, if any, strength. This indicates that cellulose and water must have some relationship to produce paper or fiberboard product.

The strength that is attained cannot be attributed alone to the inter-winding and inter-locking of the fibers during the preforming operation. Though the fibers do inter-lock to some extent and cross each other at all angles Hooper(15, p. 60) found that the fibers and groups of fibers tend to lie parallel to the surface of the board. This would tend to show a "layering" of the fibers which would produce very little strength. Bailey(2, p. 1275) concluded that fiber entanglement played only a minor role in fiber bonding while an intimate position of cellulose interfaces concomitant with the removal of water caused adhesive effects.

The strength of paper or of fiberboard is attained through the drying out of the wet pulp as it is consolidated and maximum strength is attained when the product is dried to a low moisture content. If the product is allowed to take up moisture the strength steadily decreases though not to the point of complete separation of the fibers unless mechanical means are used.

The nature of the bond between fibers when used to

make paper or fiberboard is not completely understood. Bailey(2, p. 1276), from his study of the adhesive function of lignin and cellulose, concluded that cellulose is chiefly responsible for adhesion. Campbell (5, p. 12) is of the opinion that the bond between cellulosic fibers is due to the same secondary valence forces which cause crystallization, and that the strongest, least soluble bonds are produced when the two contacting cellulose surfaces are identical in orientation.

The valence forces as referred to by Campbell are thought to be those formed by the loss of water between two hydroxyl groups of adjacent cellulose molecules. These two valence forces are then thought to unite forming an oxygen linkage between the cellulose molecules. Apparently this is the crystallization referred to by Campbell.

Clark(6, p. 383) extends this theory further in that he distinguishes between weak and strong bonds on the basis of primary and secondary linkages between hydroxyl groups. In each glucose unit of the cellulose molecule there are two secondary hydroxyl groups and one primary hydroxyl group. The linkage of secondary hydroxyl groups of adjacent chains is thought to produce a weaker link than that formed by the linkage of two primary hydroxyl groups or of a primary hydroxyl group to a secondary hydroxyl group.

The entrance of water between the micelles or aggregates of cellulose chains supposedly ruptures the weak secondary bonds and perhaps a few of the primary bonds. This weakening of the bond between micelles permits more water to enter until eventually a hydrated layer, or so-called surface solution forms in which the cellulose chains are strongly held at one end to the crystalline cellulose structure while the other end extends into the surface solution. This condition of the exposed surfaces of the fibers is commonly known as gelatinization. Mechanical action on the fiber in this condition results in the rupturing of part of the exposed chains with a resulting increase in the concentration of the surface solution.

In paper making this mechanical action is accomplished in the beaters, while in the manufacture of fiberboard it is accomplished during the refining operation though by no means to the same extent.

A study of the effect of beating on pulp has shown that there is very little if any change in the chemical properties of the pulp. There is, however, a definite change in the physical properties in that the length and diameters of the fibers are decreased, fibrillation(the formation of many fine fibrils on the otherwise smooth surfaces of the fibers) increases, and the surface of the fibers gelatinize. In spite of this apparent increase in

surface area Campbell(5, p. 12) reports that beating produces no appreciable increase in the total surface or hydration of pulp.

As an explanation for the increase in strength of paper with beating Campbell(5, p. 12) has proposed the fibrillation theory of "hydration". This theory accepts the formation of the hydrated layer on all cellulose surfaces in contact with water and proposes that fibrillation, though not increasing the total surface, does increase the external surface area of cellulose fibrils and thereby produces more contacts between cellulose layers which when dried increases the strength of the product.

Clark(6, p. 384-385) stresses the role of the cambial or primary wall of the fiber which he considers to be noncellulosic, inelastic, and incapable of adhesion except, possibly, on the inner surface. The function of heating or refining then is to rupture the primary wall which will permit increased fibrillation, reduce the diameter of the fibers, increase the external surface area and increase the concentration of the surface solution, all of which are inducive to a denser, stronger product.

When the fibers are sufficiently hydrated and fibrillated they must be brought in close enough contact so that bonding will take place. To accomplish this Bailey (2, p. 1275) contends that sufficient pressure must be

applied to overcome frictional resistance and bring the cellulose micelles close enough together to permit surface tension forces to operate. These surface tension forces were calculated by Campbell(5, p. 44) to be in the order of hundreds of atmospheres, and to be of sufficient magnitude to bring the fibers close enough together for molecular-attraction to cause adhesion.

In the manufacture of fiberboard from mechanical fiber the presence of lignin and other noncellulosic materials, the short refining time employed, and the comparatively large size of the fiber bundles would all tend to produce a much weaker bond than that developed in paper making.

GENERAL PROCEDURE

SOURCE OF LODGEPOLE PINE

The lodgepole pine which was defiberized without bark was obtained by Professor J. Grantham near Paulina Prairie, approximately forty miles south of Bend, Oregon. The wood consisted of seven bolts from 4.5 inches to 10 inches in diameter, and represented all but the top portion of the bole.

The lodgepole pine which was defiberized with bark was obtained near the top of the Santiam Pass on the Bend Highway, and consisted of several trees all less than 8 inches in diameter, and down to a minimum diameter of two inches.

PREPARATION OF WOOD

In the preparation of wood without bark a spoke shaver was used to remove all the bark, both inner and outer, from the bolts. In the second part only the hard, black, outer bark of the larger bolts was removed with a small piece of metal strap iron. The bolts were scraped with a wire brush to remove some of the black outer bark. The percentage of bark removed was very low. The outer bark was removed quite easily, and it seemed very possible that an electrically operated, stiff wire brush with a concave surface could very easily be used to remove the

outer bark from this species.

DEFIBERIZING OF WOOD

Through the courtesy of the Chapman Manufacturing Company the lodgepole pine was defiberized at their plant on an Allis Chalmers Defiberizer. The bolts were cut into 30 inch lengths and stacked in the defiberizer. Douglas fir was piled on top to add sufficient weight to the load. The blower system was freed of Douglas fir fiber before starting the defiberizer. The lodgepole pine fiber was collected at the outlet in burlap sacks.

It is interesting to note that the first lodgepole pine bolts which had been end piled out-of-doors for about two months before defiberizing gave shorter fiber and a high percentage of fines. The fiber had an average moisture content of 75 per cent. The second lodgepole pine bolts which were defiberized within a week after they were obtained gave a much longer, coarser fiber and a smaller percentage of fines. The average moisture content of this fiber was 110 per cent.

DETERMINATION OF MOISTURE CONTENT OF FIBER

Moisture content determinations were made in an electrically heated oven maintained at a temperature of 105 C., and based on a drying period of 24 hours. The weight of samples used varied from 2 to 8 grams, oven dry

basis, and all weighings were made on a single beam balance to the nearest hundreth of a gram.

$$\text{Moisture Content(MC)} = \frac{\text{Wt. Wet Fiber - Wt. Dry Fiber}}{\text{Wt. of Dry Fiber}} \times 100$$

Calculation of oven dry weight of fiber from moisture content:

$$\text{O. D. Wt. Fiber} = \frac{\text{Wt. of Wet Fiber}}{1 + \frac{MC}{100}}$$

This formula was used to calculate the weight of wet fiber of known moisture content necessary to give the desired weight of oven dry fiber.

RODMILL REFINING OF DEFIBERIZED WOOD

The fiber was refined in a rodmill at room temperature at an average consistency of three to four per cent. This was based on an oven dry weight of fiber of 400 to 450 grams in eleven liters of water contained in the rodmill when completely charged. This consistency was found to give a good range in fiber size when rodmilled for varying periods of time from ½ to 2 hours.

Considerable difficulty was experienced in securing the same weight of fiber from day to day due to the rapid change in the moisture content of the fiber, and because of the time required for moisture content determinations. This was overcome to some extent by first running preliminary moisture content determinations, then thoroughly mixing sufficient fiber in a large box, taking moisture

content samples, and then weighing out the necessary numver of charges at one time based on the preliminary moisture content. The following day the data were corrected for the change in moisture content. After two weeks of dry storage in burlap sacks the average moisture content was approximately 10 per cent, and thereafter remained constant.

The fiber was washed from the rodmill and collected on a 20 mesh wire screen. No freeness determinations were made on the stock. The wet fiber was squeezed of excess moisture by hand and placed in a small keg. Upon completion of the rodmilling the fiber was thoroughly mixed, moisture content samples were taken, and the keg was tightly covered to minimize the change in the moisture content of the fiber.

PREFORMING

The purpose of this operation is the formation of a fiber mat that may be handled and pressed to the desired form. The equipment consisted of a preforming box 5 inches by 10 inches in cross section and 3 feet high, mounted on four 1 foot legs. It was equipped with a valve and one foot of 1 inch pipe at the bottom to drain the water from the box and to produce suction to form a better mat. The fiber mat was formed on a 20 mesh wire

Screen mounted on a stiff wire frame. The wire frame rested on supports slightly above the drain pipe. Considerable loss of fiber was encountered at first due to passage of the water and fiber around the edges of the frame during drainage. This loss was reduced to a minimum by nailing rubber window stripping, large end down, above the supports. These strips held the wire frame securely in place yet permitted easy removal of the preform.

The desired weight of fiber was placed in a pail and water was slowly added with vigorous stirring to break up the lumps of fibers. The total amount of water added was from 6 to 8 liters, depending on the weight of fiber used. Up to 200 grams, oven dry weight, of fiber could be easily handled by this method. Water was admitted to the preforming box until the screen was covered. The water-fiber mixture under agitation was poured into the box. The drain was opened as soon as the water ceased moving. The preform was removed after completion of drainage of the water.

The preforms were from 1 inch to 2 inches thick, with the smallest fibers(fines) on top. Boards when pressed with the fines against the smooth steel plate had a very smooth, dark-brown surface. A wire screen was placed on the top of the preform, and the preform then inverted, screen down onto a metal plate for transfer to the press.

PRESSING

The preforms were placed in a mold and pressed in a hand operated, hydraulic press equipped with electrically heated platens. The steel mold consisted of a perforated bottom plate 5 inches by 10 inches by ½ inch, two solid top plates of the same dimensions, and an outer jacket 3/4 inches thick with a thermometer well. The mold acted as a heating chamber and helped to prevent loss of fiber around the edges during pressing. The perforated plate had small holes on top and larger ones beneath to aid in the removal of water during pressing. This action could be improved by connecting the holes and the edges of the plate with small channels.

The preform was placed screen down on the perforated plate and a polished stainless steel plate was placed on top. Both the perforated plate and stainless steel plate were coated lightly with bees wax several times a day to prevent sticking. The outer jacket was dropped around the preform, the two solid plates were placed on top and the assembly was then put in the press.

Pressures up to 500 p.s.i. were obtained with this press and mold. As means of comparison pressures of 100, 300, and 500 p.s.i. were used. Continous pumping of the handle was necessary to maintain the desired pressure.

Temperature could have been controlled to some extent

by means of a rheostat, but throughout this experiment the full flow of electrical current was utilized. In all pressings the press and mold were preheated to at least 350 F., but even then the time-temperature cycle was very long due largely to the insufficient supply of heat. Steam heated platens would have reduced the pressing time considerably and greatly increased the scope of the work. The temperatures ranged from 220°F. to 370° F.

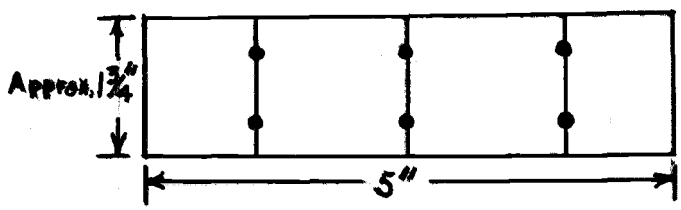
In the early work an attempt was made to press to a specified temperature but because of the great variation in the time required it was decided to press to a specified time. It was found that a temperature of 260°F. or a time of 10 minutes was necessary to secure a satisfactory fiberboard, but the time to reach this temperature varied with thickness. The time was then varied up to 40 minutes and eventually a time of 20 minutes was chosen for the latter part of the study.

PREPARATION OF SPECIMENS

The 5 inch by 10 inch fiberboards were numbered and marked for cutting into four sections in such a manner that a 1 3/4 inch specimen would be obtained from each side of a center line across the width of the board. The 1 3/4 inch samples were used for both strength and moisture absorption samples, while the end sections served as permanent color samples.

STRENGTH SPECIMENS

A micrometer was used to measure the thickness of the boards and calipers were used to measure the width. Six thickness measurements to the nearest one-thousandth of an inch, and three width measurements to the nearest one-hundredth of an inch were made at the points indicated on the diagram below. The average of these measurements was used for calculating the modulus of rupture.

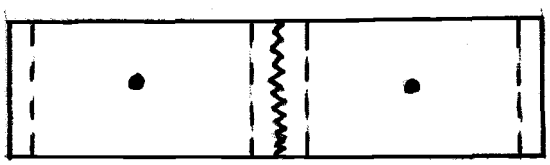


Lines represent caliper measurements.

Dots represent micrometer measurements.

MOISTURE ABSORPTION SPECIMENS

Following the strength test the samples were broken in two and the ends were trimmed so that the moisture content samples represented sections from each half of the board.



Dot represents micrometer measurement.

A circle, slightly larger than the faces of the micrometer, was marked with crayon on each specimen and all measurements were made at this one point. Each specimen was weighed to the nearest one hundredth of a gram. The specimens were then immersed in water contained in flat, 1 inch deep, pyrex dishes, and kept immersed by small glass stirring rods. Since nearly all of the swelling was found to take place through the edges of the specimens the samples were placed in the water in a flat position with spaces between the edges of the specimens.

The wet specimens were blotted with paper towels, then immediately weighed and the thickness measured. The time required for measuring each specimen was about one minute so the specimens were placed in the water a minute apart and all subsequent measurements were made in the same order.

TESTING

The modulus of rupture in bending as prescribed in Federal Specifications For Fiberboard, Hard-Pressed, Structural, LLL-F-311, March 9, 1939 was used as the basis for comparative strength values of all fiberboards. The specimens were tested on a Tinius Olsen Testing Machine using a speed of 0.01 inches per minute and a span of 4 inches. The formula for calculating the modulus of rupture is:

$$MR = \frac{3lP}{2wh^2}$$ Units = Pounds per square inch

Wherein:

l = Span in inches w = Width in inches

p = Maximum load h = Thickness in inches

MOISTURE ABSORPTION AND SWELLING

Moisture absorption and swelling tests were based on the initial weight and thickness of the board. A standard absorption time of 24 hours was used as a basis for comparison, and the results were expressed as a per cent of initial weight and thickness.

Per cent absorption $\frac{\text{Wt. of Immersed Sample-Initial Wt.}}{\text{Initial Wt.}} \times 100$

Per cent swelling $\frac{\text{Thickness(Wet) - Initial Thickness}}{\text{Initial Thickness}} \times 100$

DENSITY

Density calculations were based on the weight of the board immediately after pressing, and the thickness of the strength test sample.

Density $\frac{\text{Wt. Board x 1728}}{\text{Thickness x 50 x 453.6}}$ $\frac{\text{Wt. Board x 0.0762}}{\text{Thickness}}$

(Area of Board 50 square inches)

PRELIMINARY STUDY OF PRESSING CONDITIONS

During the hot-pressing operation the water is removed by pressure and by evaporation. In order to determine what proportion of the water was removed by each, five preforms, containing 80 to 139 grams of fiber refined for 0.5 hours at 3.5 per cent consistency, were weighed and pressed at room temperature at pressures of 50, 100, 200, 300, 400, and 500 p.s.i. The preforms were reweighed after pressing at each of the above pressures. They were then oven dried for 24 hours at 105°C. and the moisture content of the preforms at each pressure was calculated.

The results are shown in Table 6, page 45. The origional moisture content of the preforms was 982 per cent. Upon completion of the pressing series the moisture content was reduced to 100 per cent. Seventy-nine per cent of the water was removed at a pressure of 100 p.s.i., 87 per cent was removed at a pressure of 300 p.s.i., and 89 per cent was removed at a pressure of 500 p.s.i.

Since only 80 to 90 per cent of the water is removed by pressures of 100 to 500 p.s.i. the remaining 10 to 20 per cent must be removed by evaporation.

At pressing temperatures above 212°F. part of the water in the board is in the form of steam. Incomplete

removal of this steam by too short a pressing time for the temperature developed resulted in delamination of the boards. In some cases the delamination was complete while in others there was only partial delamination or a slight blistering of the surfaces of the board. The pressing time - temperature relationship should be such as to permit complete removal of the steam and it seems plausible that additional time should be allowed to permit the boards to set or "cure".

To secure rapid evaporation and to reduce the pressing time to a minimum a fairly high temperature is desirable. With the press used there was practically no control over temperature and higher temperatures could only be obtained by increasing the pressing time. The temperature developed at any given pressing time increased with increased pressure and varied considerably at each pressure. In order to obtain comparable time - temperature schedules the press was preheated to 360° F. and reheated to this temperature after pressing two or three boards.

To determine the pressing conditions that should be used the preforms were pressed for periods of time from 1 to 18 minutes, and to predetermined temperatures from 220° to 340°F.

Boards less than .100 inch in thickness were successfully pressed at 300 p.s.i. using a pressing time

of 6 minutes. The temperature ranged from 226° to 242° F. To produce satisfactory boards greater than .100 inch in thickness at this pressure the minimum pressing time was found to be approximately 1 minute per 0.01 inch of board thickness or 1 minute per 8 grams of fiber. At a pressure of 100 p.s.i. the pressing time was roughly 1 minute per 7 grams of fiber, and at 500 p.s.i. the pressing time was 1 minute per 10 grams of fiber.

Good boards were pressed at both 300 and 500 p.s.i. with a pressing time of 9 minutes and a temperature of 240° F., and at 100 p.s.i. with a pressing time of 14 minutes and a temperature of 260° F. However, to consistently press good boards using weights of fiber from 99-138 grams a temperature of 300° F. was found to be desirable. This required a minimum pressing time of 20 minutes at a pressure of 100 p.s.i., and 15 minutes at pressures of 300 and 500 p.s.i.

TABLE 6

THE EFFECT OF PRESSURE ON THE MOISTURE CONTENT OF PREFORMS AT 22 C.

Pressure p.s.i.	Water Removed per cent	Moisture Content of Preforms(%)
0	0	982
50	70	314
100	79	218
200	85	156
300	87	130
400	88	119
500	89	100

Number of Samples - 5

Average Weight of Fiber - 95 grams

THE EFFECT OF REFINING TIME ON THE PROPERTIES OF BARK-FREE FIBERBOARD

PROCEDURE

The fiber was refined at 3.6 per cent consistency for periods of 0.5, 1.0, and 2.0 hours, and 140 gram samples of the refined fiber were preformed and pressed at a pressure of 500 p.s.i. for 20 minutes. Two boards were pressed from each type of fiber.

RESULTS(Table 7 page 48)

Strength increased continuously with increased refining time. The greatest increase in strength occured during the first hour of refining. The strength developed at 1 hour refining was 5530 p.s.i., while that developed at 2 hours refining was 5990 p.s.i. Strength increased 105, 105, 23, and 3 per cent with each increase in refining time of 0.5 hour. The total increase in strength over unrefined fiber was 236 per cent. Strength increased 63 per cent with an increase in refining time from 0.5 to 1.5 hours.

Swelling and absorption decreased with increased refining time up to 1.0 hours and thereafter remained relatively constant. The swelling and absorption values at a refining time of 1 hour were 37 per cent and 60 per cent respectively. Swelling decreased 31 per cent and 15

per cent during the first and second 0.5 hour refining periods. Absorption decreased 39 and 21 per cent during the same periods. Swelling and absorption decreased 16 per cent and 22 per cent respectively with an increase in refining time from 0.5 to 1.5 hours.

Thickness decreased with increased refining time due to the increased loss of fiber during the preforming operation.

The amount of fiber recovered from the rodmill on a twenty mesh screen decreased an average of 10 per cent with each 0.5 hour of refining(Table 8, page 49).

The best appearing boards were those made from fiber that had been refined for 1 hour. These boards were light gray in color and had a hard smooth surface in which the individual fibers or fiber bundles were not readily distinguishable. Boards produced from unrefined fiber or fiber refined for 0.5 hour were light brown in color and the individual fiber bundles were very noticeable. Refining periods above 1 hour produced boards which were dark gray in color.

TABLE 7

THE EFFECT OF REFINING TIME ON THE PROPERTIES OF FIBERBOARD

Refining Charge: 400 grams

Pressure: 500 p.s.i.

Pressing Time: 20 minutes

Number of Samples: 2

Refining Time (Hours)	Temp. °F.	Thickness Inches	Modulus of Rupture (p.s.i.	Absorption %	Swelling %
0	310	.162	1780	123	83
0.5	312	.162	3650	84	52
1.0	312	.155	5530	63	37
1.5	310	.149	5940	62	36
2.0	315	.137	5990	65	36

TABLE 8

THE EFFECT OF REFINING TIME ON THE PER CENT OF FIBER RECOVERED ON A 20 MESH SCREEN

Refining Time Hours	Fiber Recovered %
0.5	92
1.0	80
1.5	74
2.0	58

THE EFFECT OF REFINING TIME AND PRESSURE ON THE PROPERTIES OF FIBERBOARD CONTAINING BARK

PROCEDURE

The bark-containing fiber was refined at 3.6 per cent consistency for 0.5, 100, 1.5, and 2.0 hours. Samples of the refined fiber weighing 131 grams were pressed for 20 minutes at pressures of 500, 300, and 100 p.s.i. A very small amount of sodium hydroxide, less than 1 gram, was added to each charge during refining to counteract the darkening effect of the bark.

RESULTS(Table 9, page 53)

Strength increased continuously with increased refining time at all pressures. The variation in the results obtained at a pressure of 100 p.s.i. is attributed to the variation in the thickness of boards. At a pressure of 300 p.s.i. strength increased steadily with increased refining. At a pressure of 500 p.s.i. strength increased with increased refining time up to 1.5 hours. There was only a slight increase in strength with a refining time of 2 hours. Strength increased 59 per cent at a pressure of 500 p.s.i., 72 per cent at a pressure of 300 p.s.i., and 15 per cent at a pressure of 100 p.s.i., with an increase in refining time from 0.5 hours to 1.5 hours.

Strength increased with increased pressure. The

greatest increases in strength occured in fiber that had been refined for one hour, and the least increase occured in fiber that had been refined for 0.5 hour. The strength of boards made from fiber refined for 1 hour increased 50 per cent with an increase in pressure from 100 to 300 p.s.i., and 93 per cent with an increase in pressure from 100 to 500 p.s.i.

Swelling and absorption decreased steadily with increased refining time at all pressures. An increase in refining time from 0.5 to 1.5 hours resulted in a decrease of 13 per cent and 16 per cent in swelling and absorption at 500 p.s.i., a decrease of 12 per cent and 23 per cent at 300 p.s.i., and a decrease of 17 per cent and 63 per cent at 100 p.s.i.

Swelling and absorption decreased with increased pressure. An increase in pressure from 100 to 300 p.s.i. resulted in an average decrease in swelling of 8 per cent and a decrease in absorption of 41 per cent. An increase in pressure from 300 to 500 p.s.i. reduced absorption an average of 9 per cent but had no effect on swelling.

The best appearing boards were those made from fiber that had been refined for 1 hour. The dark brown flakes of bark were tightly bonded in place, and were of such a size as to produce a good contrast with the light brown gackground. Boards made from fiber that had been refined for 1.5 and 2.0 hours were dark gray in color and the

flakes of bark were too small to be easily noticeable. Boards made from fiber refined for 0.5 hour were light brown in color, the fiber bundles were visible, and the larger flakes of bark tended to loosen.

The presence of bark had little or no effect on the swelling and absorption of the fiberboard, but it did increase the strength of the boards slightly. The strength was increased 15 per cent and 8 per cent at pressures of 300 and 500 p.s.i. respectively.

The presence of the small amount of sodium hydroxide used during refining had little effect on the swelling and absorption of the fiberboard but it was found to increase the strength of the fiberboard markedly. Strength was increased 32 per cent and 14 per cent at pressures of 300 and 500 p.s.i. respectively.

TABLE 9

THE EFFECT OF REFINING TIME AND PRESSURE ON THE PROPERTIES OF FIBERBOARD CONTAINING BARK

Refining: 400 grams

Pressing Time: 20 minutes

Number of Samples: 2

Refining Time	Temp. °F.	Thickness Inches	Modulus of Rupture (p.s.i.)	Absorption %	Swelling %
		Pressure - 500 p.s.i.			
0.5	320	.176	4610	84	52
1.0	340	.154	6470	75	43
1.5	335	.150	7330	68	39
2.0	315	.153	7580	66	35
		Pressure - 300 p.s.i.			
0.5	300	.181	3710	102	53
1.0	330	.163	5120	79	40
1.5*	310	.153	6390	79	41
2.0*	325	.153	7750	69	34
		Pressure - 100 p.s.i.			
0.5*	300	.191	3510	164	65
1.0*	320	.173	3400	117	45
1.5*	310	.181	4010	101	48

* One sample

THE EFFECT OF PRESSING TIME AND PRESSURE ON THE PROPERTIES OF FIBERBOARD WITHOUT BARK

PROCEDURE

The fiber was refined for one hour at 4 per cent consistency, weighed into 131 gram(oven dry weight) samples, and preformed. The preforms were pressed in groups of three at pressures of 500, 300, and 100 p.s.i. for pressing periods of 10, 15, and 20 minutes. The press was preheated to 360° F. before pressing each series of three. The moisture content of the fiber pressed at 100 p.s.i. was found to have changed which resulted in a correction of the weight of fiber used to 138 grams.

RESULTS(Table 10 page 58)

A minimum pressing time of 15 minutes was found to be necessary to produce satisfactory fiberboards at pressures from 100 to 500 p.s.i. Boards pressed at 500 p.s.i. for 10 minutes at temperatures of 250° to 290° F. were slightly blistered.

Density increased 21 per cent with an increase in pressure from 100 to 300 p.s.i., and 25 per cent with an increase in pressure from 100 to 500 p.s.i. The average densities at pressures of 100, 300, and 500 p.s.i. were 0.73, 0.88, and 0.92 respectively. There was no appreciable change in density with increased pressing time.

Strength increased 75 per cent with an increase in pressure from 100 to 300 p.s.i., and 100 per cent with an increase in pressure from 100 to 500 p.s.i. The average strength values at pressures of 100, 300, and 500 p.s.i. were 2450, 4100, and 4680 p.s.i. respectively.

Strength increased with increased pressing time at all pressures. At a pressure of 300 p.s.i., however, strength decreased 3 per cent with an increase in pressing time from 15 to 20 minutes. A similar change in pressing time at pressures of 100 and 500 p.s.i. resulted in strength increases of 13 per cent and 11 per cent respectively. With an increase in pressing time from 10 to 20 minutes strength increased 14 per cent at 300 p.s.i. and 22 per cent at 500 p.s.i.

Swelling and absorption decreased with increased pressing time. At a pressure of 500 p.s.i. swelling and absorption decreased 65 per cent and 71 per cent respectively with an increase in pressing time from 10 to 20 minutes. An increase in pressing time from 15 to 20 minutes resulted in decreases in swelling and absorption of 24 and 42 per cent at a pressure of 100 p.s.i., of 17 and 15 per cent at a pressure of 300 p.s.i., and of 29 and 28 per cent at a pressure of 500 p.s.i.

Swelling and absorption decreased with increased pressure. At a pressing time of 15 minutes, however, the

swelling and absorption values for boards pressed at 300 and 500 p.s.i. were very similar. For a pressure change from 100 p.s.i. to either 300 or 500 p.s.i. absorption decreased 57 per cent and swelling decreased 10 per cent. At a pressing time of 20 minutes both swelling and absorption decreased steadily with increased pressure. An increase in pressure from 100 to 300 resulted in a decrease in swelling of 4 per cent, and a decrease in absorption of 30 per cent. An increase in pressure from 100 to 500 resulted in a decrease in swelling of 11 per cent and a decrease in absorption of 43 per cent.

As shown on graphs 1 and 2 pages 59 and 60 the rates of absorption and swelling were greatest during the first four hours of immersion and decreased up to an immersion time of about 16 hours. Thereafter the amount of swelling and absorption was very small and the rates remained constant.

Boards pressed for the longest period of time were the most stable, but stability was further increased at higher pressures.

The average linear expansion of boards immersed for 24 hours was 1 per cent. There was no significant difference between boards pressed for varying periods of time or at varying pressures. The linear expansion for the seventeen samples used varied from 0.7 to 1.6 per cent.

Increased pressure, increased pressing time, and increased temperature produced boards that were darker in color. The boards made at a pressure of 100 p.s.i. were a grayish white in color. Boards pressed at 300 p.s.i. were slightly darker, while those pressed at 500 p.s.i. were dark gray and slightly scorched.

TABLE 10

THE EFFECT OF PRESSING TIME AND PRESSURE ON THE PROPERTIES OF FIBERBOARD

Refining: 436 grams - 1 hour

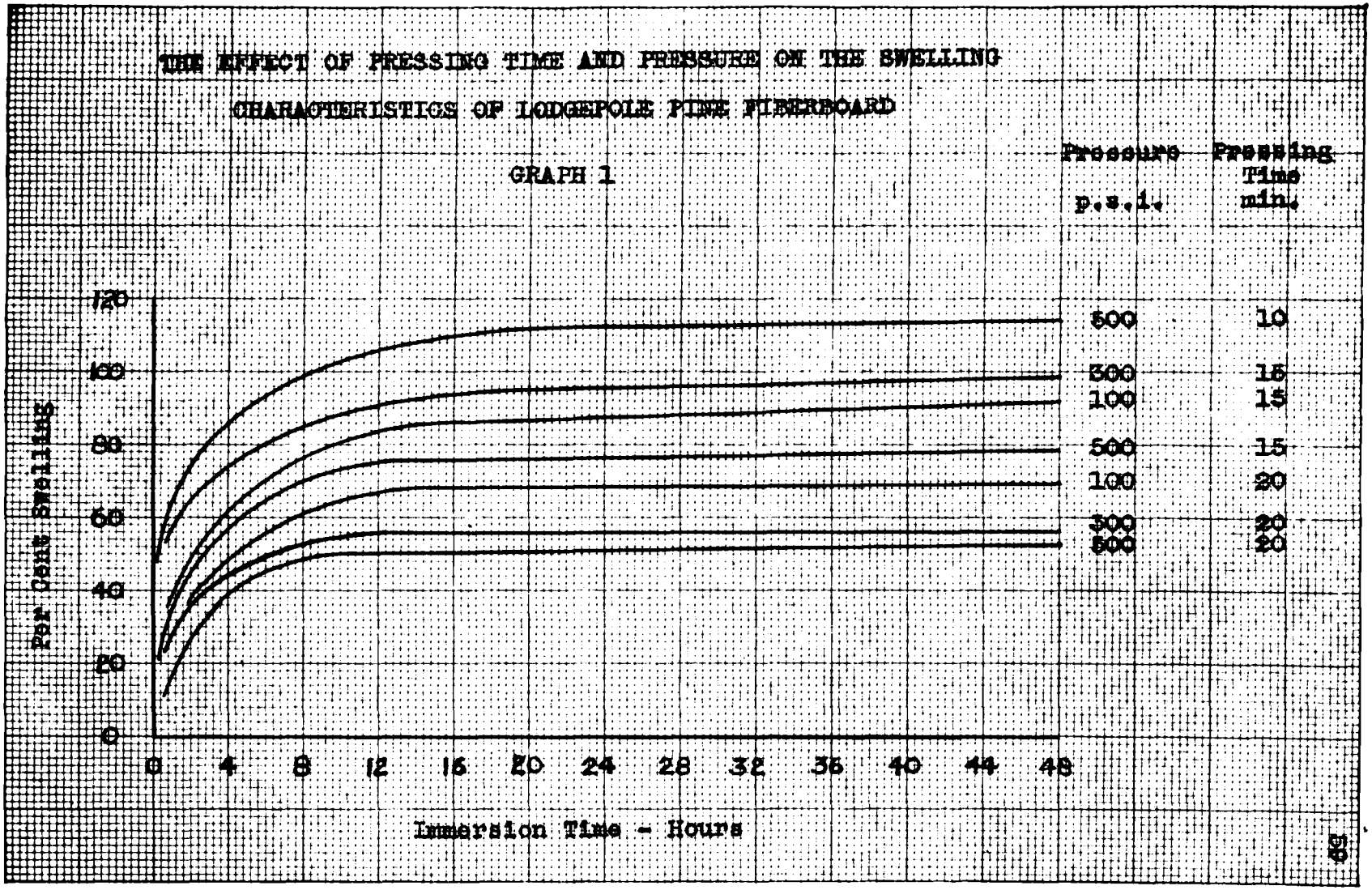
Number of Samples: 3

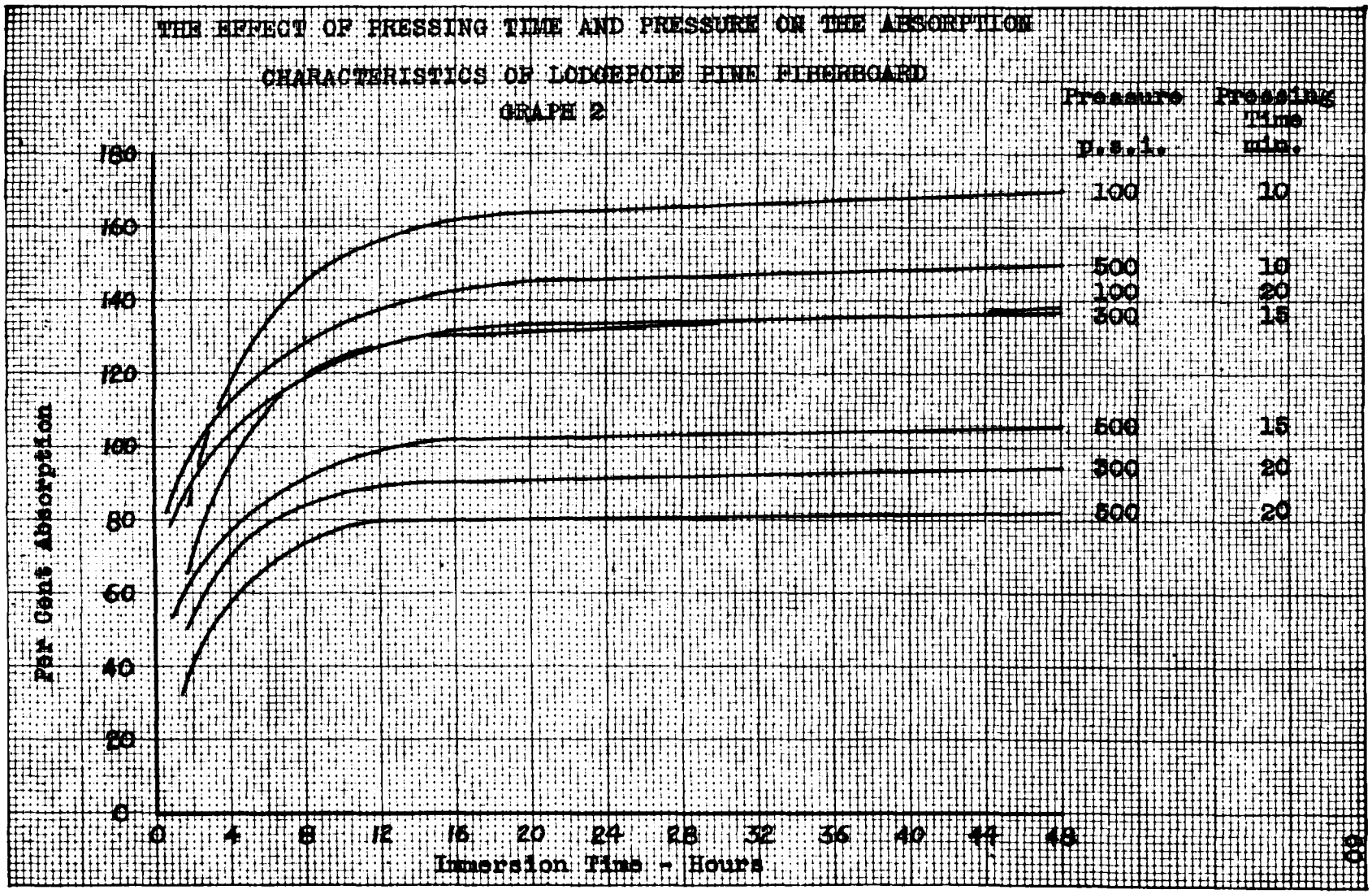
Pressing Time Min.	Temp. °F.	Thickness Inches	Density	M.R. psi	Absorp. %	Swelling %
		Pressure: 500 p.s.i.				
10	264	.158	.92	4240	146	113
15	295	.156	.91	4640	103	77
20	334	.161	.92	5160	75	48
		Pressure: 300 p.s.i.				
10*	258	.173	.89	3720	---	---
15	269	.170	.89	4360	103	72
20	297	.174	.87	4220	88	55
		Pressure: 100 p.s.i.				
15	261	.215	.72	2300	160	83
20	300	.202	.75	2600	118	59

*1 sample - 2 boards delaminated

THE EFFECT OF PRESSING TIME AND PRESSURE ON THE SWELLING CHARACTERISTICS OF LODGEPOLE PINE FIBREBOARD

GRAPH 1




THE EFFECT OF PRESSING TIME AND PRESSURE ON THE ABSORPTION CHARACTERISTICS OF LODGEPOLE PINE FIBERBOARD
GRAPH 2
Pressure p.s.i.
Pressing Time min.
100 10
500 10
100 20
300 15
500 15
300 20
500 20
Per Cent Absorption
180
160
140
120
100
80
60
40
20
0
0 4 8 12 16 20 24 28 32 36 40 44 48
Immersion Time - Hours

THE EFFECT OF PRESSING TIME AND PRESSURE ON THE RESISTANCE OF THE SURFACES OF FIBERBOARD TO WATER

When sections of fiberboard were immersed in water the initial swelling was found to occur at the edges with the formation of a definite ridge which moved rapidly toward the center of the board. In the denser boards this effect was much less noticeable.

Apparently little if any of the initial absorption had taken place through the surfaces of the board. To determine the moisture resistance of the surfaces one cubic centimeter of water was run from a burette onto the surfaces of small sections of boards. These were then covered with large watch glasses and the time required for complete absorption was recorded. The results are shown in Table 11, page 63.

The rough or bottom surface of the boards were found to be much more resistant to water than the smooth surfaces. Once absorption began on either surface it proceeded very rapidly with the formation of a welt similar in shape to the area occupied by the water. Absorption on the smooth surface apparently took place uniformly over the area occupied by the drop for this area was wet. On the rough surface, however, the area was not wet, indicating that absorption had taken place through small cracks or crevices.

The shortest time required for complete absorption was 5 minutes on the smooth surface and 2.2 hours on the rough surface. In one sample no absorption had occured on the smooth surface in 24 hours. In this sample the plates in the mold had probably received a fresh coating of wax before the board was pressed.

Boards pressed for twenty minutes were more resistant to moisture than boards pressed for fifteen minutes. Boards pressed for ten minutes were the least resistant. The resistance of the boards to moisture tended to increase with increased pressure but a large portion of this effect can be attributed to the higher temperatures developed at the higher pressures. In this respect it is of interest to note that boards pressed at approximately 300 C. at each of the three pressures irrespective of pressing time had absorption times of 1, 1.1, and 1.2 hours. The absorption time increased slightly with increased pressure.

TABLE 11

THE RESISTANCE OF THE SURFACES OF FIBERBOARD TO WATER

Number of Samples	Pressure (psi)	Pressing Time (psi)	Temp. °F.	Time to Absorb 1cc. of H_2O Hours	
				Smooth	Rough
2	100	15	261	0.1	2.2
3	100	20	300	1.0	6
2	300	10	252	0.4	---
1	300	15	269	0.4	---
3	300	20	297	1.1	6
1	500	10	288	0.1	---
1	500	15	298	1.2	---
3	500	20	334	2.5	6

THE EFFECT OF PRESSING TIME ON THE PROPERTIES OF BARK-FREE FIBERBOARD

PROCEDURE

To determine the effect of longer pressing times on fiberboard 123 gram samples of fiber refined at approximately 3.6 per cent consistency for one hour were preformed and pressed at 500 p.s.i. for pressing periods of 10, 20, 30, and 40 minutes. Two boards were made at each pressing period. The press was preheated to 360°F. before pressing each pair.

RESULTS(Table 12 page 66)

A pressing time of 10 minutes was insufficient for complete bonding as indicated by the greater thickness, lower strength, high swelling and absorption values, and blistering of the boards.

At and above a pressing time of 20 minutes both thickness and strength remained relatively constant. The average thickness was .142 inches, and the average strength was 5730 p.s.i.

Swelling and absorption decreased with increased pressing time up to 30 minutes and thereafter remained constant. The absorption and swelling values at 30 minutes were 54 per cent and 26 per cent respectively. Absorption and swelling decreased 89 per cent and 78 per cent

respectively with an increase in pressing time from 10 to 30 minutes.

TABLE 12

THE EFFECT OF PRESSING TIME ON PROPERTIES OF FIBERBOARD

Refining: 400 grams - 1 hour

Pressure: 500 p.s.i.

Number of Samples: 2

Pressing Time (Min.)	Temp. °F.	Thickness Inches	Modulus of Rupture	Absorption %	Swelling %
10	259	.147	4800	143	105
20	320	.141	5860	69	40
30	352	.143	5470	54	26
40	370	.141	5850	53	27

THE EFFECT OF PRESSURE AND WEIGHT OF FIBER ON THE DENSITY OF FIBERBOARD
(Table 13 page 68)

The average density of fiberboard pressed at 100, 300, and 500 p.s.i. was 0.71, 0.84, and 0.90 respectively.

Density increased 18 per cent with an increase in pressure from 100 to 300 p.s.i., and 27 per cent with an increase in pressure from 100 to 500 p.s.i.

At a pressure of 100 p.s.i. the average increase in density with an increase in the weight of fiber from 99 to 138 grams was 7.4 per cent. The average increases at pressures of 300 and 500 p.s.i. were 4.8 per cent and 5.7 per cent respectively. The average increase for all pressures was 6 per cent.

THE EFFECT OF PRESSURE AND WEIGHT OF FIBER ON THE DENSITY OF FIBERBOARD

Pressure p.s.i.	Number of Samples	Average Weight of Board(grams)	Density
100	13	106	.71
300	28	106	.84
500	15	107	.90

Pressure p.s.i.	Wt. of Fiber	Number of Samples	Density	Increase in Density %
100	99	5	.68	7.4
100	138	8	.73	
300	99	12	.83	4.8
300	138	3	.87	
500	99	6	.88	5.7
500	138	2	.93	

THE EFFECT OF WEIGHT OF FIBER ON THE PROPERTIES OF FIBERBOARD

PROCEDURE

The bark - free fiber was refined for 1 hour at 3.6 per cent consistency. Samples of the refined fiber weighing 83, 123, 163, and 203 grams(oven dry basis) were pressed for twenty minutes at pressures of 300 and 500 p.s.i.

RESULTS(Table 14 page 71)

The temperature developed in the press decreased steadily as the weight of fiber increased. A pressing time of 20 minutes was sufficient for pressing up to 203 grams of fiber at 500 p.s.i., but was insufficient for pressing a similar weight of fiber at 300 p.s.i.

There was no significant change in strength with change in weight of fiber at a pressure of 500 p.s.i. The average strength at this pressure was 5910 p.s.i. At a pressure of 300 p.s.i., however, strength increased steadily with increased weight of fiber from 82 to 163 grams.

Thickness increased an average of .044 inch with each additional 40 grams of fiber at 500 p.s.i., and .047 inch at 300 p.s.i. The average difference in thickness between boards pressed at the two pressures was .017 inch.

At a pressure of 500 p.s.i. there was no significant

change in swelling and absorption until the weight of fiber exceeded 163 grams. The average swelling and absorption for weights of fiber from 83 to 163 grams pressed at 500 p.s.i. was 35 per cent and 61 per cent respectively. An increase in the weight of fiber to 203 grams increased the swelling and absorption 13 per cent and 16 per cent respectively.

At a pressure of 300 p.s.i. there was no significant change in swelling and absorption until the weight of fiber exceeded 123 grams. The average swelling and absorption for weights of fiber of 83 and 123 grams was 38 and 77 per cent respectively. An increase in the weight of fiber to 163 grams increased the swelling and absorption 9 per cent and 7 per cent respectively.

The per cent swelling at a pressure of 300 p.s.i. was 3 per cent higher than at a pressure of 500 p.s.i. Absorption was 15 per cent higher.

TABLE 14

THE EFFECT OF WEIGHT OF FIBER ON THE PROPERTIES OF FIBERBOARD

Refining: 400 grams - 1 hour

Pressing Time: 20 minutes

Number of Samples: 2

Oven Dry Weight of Fiber (Grams)	Temp. °F.	Thickness Inches	Modulus of Rupture (psi)	Absorption %	Swelling %
		Pressure: 500 p.s.i.			
83	330	.100	5740	65	35
123	325	.141	5960	59	35
163	312	.188	6090	60	36
203	302	.232	5850	76	49
		Pressure: 300 p.s.i.			
83*	347	.122	2520	78	38
123*	325	.160	3750	75	37
163*	300	.206	4590	82	46
203*	295	----------Delaminated----------			

*1 sample

THE EFFECT OF ACIDS AND BASES ON THE PROPERTIES OF FIBERBOARD

During the course of the study occassional samples of fiber were refined in NaOH and H_2SO_4, and other samples were treated with H_2SO_4, NaOH, and HNO_3 prior to preforming. The results are shown in Table 15, page 73.

NaOH was found to increase the strength of fiberboard considerably, but to have little or no effect on the swelling and absorption of fiberboard. Dilute solutions (0.05 per cent) increased the strength of boards as much as 14 per cent. Stronger solutions(1 per cent) increased the strength 34 per cent.

HNO_3 and H_2SO_4 were found to have little or no effect on the strength of fiberboard, and to decrease the swelling and absorption of fiberboard markedly. Dilute solutions (0.2 per cent) of both acids reduced swelling to about 25 per cent, and stronger concentrations(1 per cent) reduced the swelling to 12 per cent.

The color of boards treated with both acids and bases was lightened and the appearance of the boards improved.

Boards produced from fiber refined in NaOH were light to medium brown in color. H_2SO_4 tended to bleach or whiten the boards. Boards made from fiber preformed in HNO_3 were yellowish-brown in color.

TABLE 15

THE EFFECT OF ACIDS AND BASES ON
THE PROPERTIES OF FIBERBOARD

Pressure: 300 p.s.i. Refining Time: 1 hr.

Preforming Conditions	Thickness (Inch)	Strength p.s.i.	Absorption %	Swelling %
Natural	.160	3750	75	37
Dil. HNO	.151	3940	58	23
Dil. NaOH	.151	3990	86	47

Pressure: 500 p.s.i. Refining Time: 1.5 hrs.

Refining Conditions	Thickness	Strength	Absorption	Swelling
Natural	.151	6420	65	33
Dil. H SO	.158	5910	64	29
Dil. NaOH	.150	7330	68	38

Pressure: 500 p.s.i. Refining Time: 1 hr.

Natural	.156	4640	103	77
Strong H SO	.102	4580	42	12
Strong NaOH	.155	6430	98	70

SUMMARY

EFFECT OF INCREASED REFINING TIME

1. Strength increased with increased refining time.

Boards made from fiber refined for 2 hours and pressed at 500 p.s.i. were 236 per cent stronger than boards made from unrefined fiber. Strength increased 210 per cent during the first hour of refining. The strength of both bark free and bark containing boards increased an average of 61 per cent 2 per cent with an increase in refining time from 0.5 to 1.5 hours.

Boards pressed at 300 p.s.i. increased 72 per cent in strength during the same period. Boards pressed at 100 p.s.i. increased only 15 per cent in strength.

2. Swelling and absorption decreased with increased refining time.

The swelling of boards made from bark free fiber and pressed at 500 p.s.i. was reduced 46 per cent with a refining period of 1 hour. Absorption was reduced 60 per cent. There was little or no change in either swelling or absorption beyond the refining time of 1 hour.

The swelling of boards made from either bark free or bark containing fiber and pressed at 500 p.s.i. was reduced 15 per cent with an increase in refining time from 0.5 to 1.5 hours. Absorption decreased about 19 per cent

during the same period.

An increase in refining time from 0.5 to 1.5 hours reduced swelling 13 per cent, 12 per cent, and 17 per cent at pressures of 500, 300, and 100 p.s.i. respectively. At the same pressures absorption was reduced 16, 23, and 63 per cent respectively.

3. The best appearing boards were those made from either bark free or bark containing fiber that had been refined for 1 hour.

4. The amount of fiber lost through a twenty mesh screen increased 10 per cent with each additional 0.5 hour refining period.

EFFECT OF INCREASED PRESSURE

1. Strength increased with increased pressure.

The strength of boards made from bark free fiber increased 75 per cent with an increase in pressure from 100 to 300 p.s.i., and 100 per cent with an increase in pressure from 100 to 500 p.s.i.

The strength of boards made from bark containing fiber increased 50 per cent with an increase in pressure from 100 to 300 p.s.i., and 93 per cent with an increase in pressure from 100 to 500 p.s.i.

2. Density increased with increased pressure.

Density increased 18 per cent with an increase in pressure from 100 to 300 p.s.i., and 27 per cent with an increase in pressure from 100 to 500 p.s.i.

3. Swelling was reduced slightly with increased pressure.

The swelling of boards made from bark free fiber decreased 4 per cent with an increase in pressure from 100 to 300 p.s.i., and 11 per cent with an increase in pressure from 100 to 500 p.s.i.

The swelling of boards made from bark containing fiber decreased 8 per cent with an increase in pressure from 100 to 300 p.s.i. A pressure of 500 p.s.i. had no further effect on swelling.

4. Absorption decreased with increased pressure.

The absorption of boards made from bark free fiber was reduced 30 per cent with an increase in pressure from 100 to 300 p.s.i., and 13 per cent with an increase in pressure from 300 to 500 p.s.i.

The absorption of boards made from bark containing fiber was reduced 41 per cent with an increase in pressure from 100 to 300 p.s.i., and 9 per cent with an increase in pressure from 300 to 500 p.s.i.

5. Thickness decreased an average of .017 inch with an increase in pressure from 300 to 500 p.s.i. The decrease ranged from .012 inch for a weight of fiber of 83 grams

to .018 inch for a weight of fiber of 163 grams. The decrease in thickness with an increase in pressure from 100 to 300 grams is estimated to be from .026 to .036 inch.

6. The resistance of the surfaces of fiberboard to moisture was increased slightly with increased pressure.

7. Lighter color boards were produced at pressures of 100 and 300 p.s.i. The boards pressed at 500 p.s.i. were darkened and often scorched.

THE EFFECT OF INCREASED PRESSING TIME-TEMPERATURE RELATIONSHIPS

1. Strength increased with increased pressing time up to that time-temperature relationship necessary for complete removal of moisture from the board.

At 500 p.s.i. strength increased with increased pressing time up to 20 minutes and thereafter remained nearly constant. The temperatures ranged from 320 to 334 F. Strength increased an average of 22 per cent with an increase in pressing time from 10 to 20 minutes.

The greatest increase in strength with increased pressing time occured at a pressure of 500 p.s.i. and the least at a pressure of 100 p.s.i.

2. Swelling and absorption decreased with increased pressing time.

At a pressure of 500 p.s.i. swelling and absorption

decreased with increased pressing time up to 30 minutes and thereafter remained constant. Swelling decreased 78 per cent and absorption decreased 89 per cent with an increase in pressing time from 10 to 30 minutes. An increase in pressing time from 20 to 30 minutes reduced swelling 14 per cent and absorption 15 per cent.

An increase in pressing time from 15 to 20 minutes reduced swelling and absorption 24 and 42 per cent at a pressure of 100 p.s.i., 17 and 15 per cent at 300 p.s.i., and 29 and 28 per cent at 500 p.s.i.

3. The resistance of the surfaces of fiberboards to moisture was increased markedly with increased pressing time.

4. The color of the boards was darkened at higher temperatures. Boards produced at temperatures below 300°F. were light gray in color. Boards produced at temperatures above 300° tended to be more brown in color.

5. Density was unaffected by increased pressing time.

THE EFFECT OF INCREASED WEIGHT OF FIBER

1. Strength was unaffected by increased weight of fiber at 500 p.s.i., but strength increased with increased weight of fiber when pressed at 300 p.s.i. This tendency was also noted at 100 p.s.i.

The strength of boards pressed at 300 p.s.i. increased 82 per cent with an increase in the weight of fiber from 83 to 163 grams.

2. The swelling and absorption of boards pressed at 500 p.s.i. were unaffected until the weight of fiber exceeded 163 grams. The swelling and absorption of boards pressed at 300 p.s.i. were unaffected until the weight of fiber exceeded 123 grams.

An additional 40 grams of fiber increased swelling 13 per cent and absorption 16 per cent at a pressure of 500 p.s.i. At a pressure of 300 p.s.i. swelling was increased 9 per cent and absorption 7 per cent.

3. Thickness increased an average of .044 inch with each 40 gram increase in the weight of fiber at a pressure of 500 p.s.i., and .047 inch at a pressure of 300 p.s.i.

4. Density increased an average of 6 per cent with an increase in the weight of fiber from 99 to 138 grams. Density increased 7.4 per cent at 100 p.s.i., 4.8 per cent at 300 p.s.i., and 5.7 per cent at 500 p.s.i.

THE EFFECT OF BARK

1. The strength of boards containing bark was slightly higher than boards without bark. Strength was 15 per cent higher at a pressure of 500 p.s.i. and 8 per cent higher

at 300 p.s.i.

2. Swelling and absorption were unaffected by the presence of bark.

3. The appearance of the boards was improved by the dark-brown bark flakes. The best appearing boards were produced with a refining time of one hour.

THE EFFECT OF ACIDS AND BASES

1. Strength was unaffected by the addition of H_2SO_4 or HNO_3 to the water during refining or preforming.

Strength was increased from 14 to 34 per cent by the addition of NaOH.

2. Swelling and absorption were reduced by the addition of H_2SO_4 or HNO_3. Swelling was reduced to as low as 12 per cent by the addition of acid without affecting the strength.

3. The color of the boards was improved by the acids and bases used. Boards made from fiber refined in NaOH were brown. H_2SO_4 tended to bleach the boards, while boards preformed in HNO_3 were yellowish-brown in color.

CONCLUSIONS

1. Increased refining time increases the strength and stability of fiberboard to a marked extent.

2. Increased pressure increases the density and strength of fiberboard markedly and increases the stability of fiberboard slightly.

3. Increased pressing time-temperature cycles beyond those necessary for complete bonding increase the stability of fiberboard to a marked extent, have little effect on strength, and tend to produce darker colored boards.

4. Increased weight of fiber increases the strength of fiberboard at lower pressures and increases the density of the boards slightly at all pressures.

5. The presence of bark has little or no effect on the strength and stability of fiberboard.

6. Acid solutions increase the stability of fiberboard with little or no reduction in strength.

7. Alkaline solutions increase the strength of fiberboard with little or no reduction in stability.

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