THE DURABILITY OF A TWO SPECIES PARTICLE BOARD

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THESIS

ABSTRACT

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PARTICLE BOARD

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This study was undertaken to determine if a durable species could protect a non-durable species when the two were combined in particle board. Two durable woods, redwood (Sequoia sempervirens (D. Don) Endl.) and northern white cedar (Thuja occidentalis L.) were mixed with jack pine (Pinus banksiana Lamb.) in varying percentages to see if a durable board could be produced.

Other factors investigated with redwood only were; 1) the effect of heat on board durability, 2) the effect of adhesive (urea-formaldehyde and phenol-formaldehyde) on durability, and 3) the decay due to different organisms.

The durability criterion was the weight loss of the blocks after exposure in soil block decay chambers. The primary decay agent used was Lenzites trabea; the fungus Polyporus versicolor was used on certain redwood blocks.

A supplementary test was undertaken, in which thin pine veneers were fastened securely to blocks of redwood. This was to determine if the redwood could protect a non-durable species in close contact with it.

The results show that, with the manufacturing methods used, the durable wood imparts no protection to the non-durable species when the two are combined in particle board. The results of the test with

thin pine veneers showed that with sufficient moisture movement after contact, the redwood did impart a protective action.

The supplementary tests with redwood only, showed that; 1) boards produced with urea-formaldehyde adhesives are less durable and more severely delaminated than blocks produced with phenol-formaldehyde adhesives, 2) the heat used did not impair the decay resistance of the redwood extractives, and 3) Polyporus versicolor is a less severe decay agent than Lenzites trabea for the species tested.

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By

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INTRODUCTION

The purpose of this study was to establish whether a small percentage of durable wood could protect a particle board comprised largely of a non-durable species. A preliminary study indicated this principle might prove true.

Two durable species were chosen; redwood (Sequoia sempervirens (D. Don) Endl.) and northern white cedar (Thuja occidentalis L.). These two species were to be mixed with jack pine (Pinus banksiana) in varying percentages.

Particle board is not now widely used in places where decay resistance is an important factor. If a board could be produced in the above manner, which had good decay resistance, it could expand the uses of particle board without greatly increasing the cost.

A second test was undertaken to learn more about how durable wood could protect a non-durable wood, if indeed it does. Thin veneers of a non-durable wood were fastened to a durable wood and tested for decay resistance. These veneers were varied in thickness to see how far this protective action, if any, could extend into the non-durable species. This test was meant to substantiate the results of the test on the particle board.

The soil block test was chosen as the criterion of durability. This method of testing has been questioned as a valid method of determining decay resistance, however it is widely used and its usefulness is recognized by many authorities.

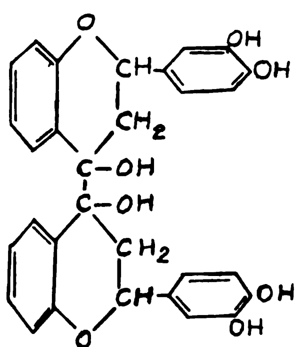
REVIEW OF LITERATURE

Wood Extractives:

The extractive content of wood is the primary factor in a wood's durability. The makeup and chemistry of these extractives is very complicated and the exact structure of many is not known.

Of the two durable woods used in this work, only the extractives of redwood have been investigated to any great extent. One of the most complete studies of redwood extractives was carried out by The Institute of Paper Chemistry (1). In this work, they found that redwood extractives contained the following four classes of materials: 1) coloring matter, which included phlobaphene, tannin, sequoyin, humic acid material, and a material resembling tannin, but differing in that it is insoluble in ethyl acetate, 2) sugars and polysaccharides, 3) cycloses (pinite and sequoyite), and 4) mineral salts. Of these four groups, only the coloring matter portion is toxic to fungi and the only fraction of the coloring matter found to be toxic was the tannin (1).

The tannin content of redwood varies and has been reported by different investigators as being between 4 and 12 per cent (1, 2, 3). The structure of tannin is not known exactly, however many complicated structures have been proposed for it. One of these which has been synthesized and found to be qualitatively equal to the natural pholobatannins is bis-(7, 3', 4' trihydroxyflavopinacol) I. (2).



I.

Tannins extracted from wood are never obtained as a pure substance, but rather as a heterogeneous mixture. Tannins have the following properties in common (2): 1)all are polyhydroxylic phenols, 2) tannins are soluble in water, alcohol, acetone, and ethyl acetate, and 3) are easily oxidized and give characteristic colorations or precipitates with metallic salts.

Tannin is found in wood, bark, leaves, and cones of trees. These tannins are not all of the same structure and the difference is usually quite distinct (2).

The toxicity of tannin is not great when compared with chemicals such as sodium pentachlorophenate. Data have shown that 823 times as much tannin by weight as sodium pentachlorophenate is required to inhibit fungus growth (1). Therefore, it is only the very high percentage of tannin found in redwood that is responsible for its durability. In tests carried out on an agar medium containing 2.058 per cent tannin extracted from redwood, no growth of the fungus Fomes annosus was observed. As stated earlier, only the tannin fraction inhibited fungus growth to any great extent.

The extractive content of northern white cedar is not as well known as that of redwood. Compounds which have been identified in northern white cedar are: α and γ thujaplicins, cedrol, white cedar oil, and traces of thujic acid (2, 3, 4). The α thujaplicin is present in concentrations of 0.08 percent compared to o.008 percent for γ thujaplicin. The thujic acid, present only in trace amounts in northern white cedar, is the major constituent in western red cedar (Thuja plicata D. Don) extractives (4).

The extractive content in redwood or any species will vary with position in the stem and age of the tree. The extractive content is greatest in newly formed heartwood at the lower portion of the stem. The extractive content decreases going up the stem or toward the pith. Two possible reasons for this are given by Scheffer and Hopp (5); they suggest 1) "That a greater quantity of the resistance factor is produced per unit of newly formed heartwood each year and that this resistance factor is not stable but subsequently deteriorates in effectiveness with age" or 2) "that the quantity of the resistance factor produced for a unit of new heartwood is about the same from year to year, but is supplemented by a continuous outward diffusion or migration of previously formed resistance factor."

The position of the extractives within the wood has been investigated by Tarkow and Krueger (6). They found that of the hot water soluble extractives, 73 percent are found within the cell walls and the remainder in the cell openings.

That the extractives of redwood are heat labile has been shown by Anderson, Duncan, and Scheffer (7). They found no fungicidal action on extractives removed with hot water. Extractives removed with cold water and concentrated by freeze drying showed good fungicidal properties. To determine the effect on redwood durability, the above authors (7) conducted decay weight loss tests on boards dried by different methods. They found that kiln drying, with temperatures not exceeding 180 degrees Fahrenheit, decreased durability only slightly. A presteaming treatment at 212 degrees Fahrenheit for four hours prior to kiln drying reduced durability to the extent that the weight loss

increased from 2 percent to 7 percent. Solvent drying in acetone increased the weight loss to 12 percent.

Particle Board:

Particle board is a relatively new product in this country, being introduced after World War II. For this reason we do not have extensive data on the durability of particle board.

In a three year test at the U. S. Forest Products Laboratory (8), the following results were obtained: 1) phenolic resin adhesives were more durable than urea or urea-melamine adhesives, 2) increased density improved the strength and durability (tested on an outdoor test fence) and 3) painted specimens after three years' exposure on a test fence were still in good condition. It was also found in this study that increasing the amount of adhesive (phenolic and urea) or the addition of 1 percent wax improved the boards' durability.

A test of particle board durability, using the soil block test, was also conducted at the Forest Products Laboratory (9). This test, in agreement with the above study, also found that increasing the amount of urea adhesive and the addition of 1 percent wax improved the board durability. In this study, however, increasing the amount of phenolic adhesive or increasing the density appeared to have no effect on the durability.

One board tested in the above study contained "About 50 percent western red cedar and 50 percent alder flakes." This board showed a very low weight loss (4 percent) when exposed to the fungus *Poria monticola*, however, when exposed to *Lenzites trabea*, the weight loss parallelled that of boards produced with low to moderate decay

resistant woods. The low weight loss was "tentatively attributed to the naturally occurring toxic extractives present in the 50 percent western red cedar flake component." The fact that the above board contained 50 percent hardwood flakes might better explain the low weight loss from exposure to Poria monticola. In all three boards in the above study, which contained hardwood flakes, the weight loss was less for Poria monticola than for Lenzites trabea. Of 14 boards in the same study containing all softwood flakes, only one lost more weight with Poria monticola. If the alder flakes were not susceptible to decay by the organisms used, the "avenues of travel" proposed later in the current study would not be present.

Much work has been done on the addition of a preservative to particle board. In most of these tests, the preservative has been incorporated in the adhesive.

In one of the early tests, Klauditz and Stolley (10) found that pentachlorophenol in a urea-formaldehyde resin produced a chipboard resistant to both fungi and termites. The amount of preservative shown to be effective was 1.5 percent of the oven dry weight of the chips.

Other investigators (11) found the optimum percentage to be 5 percent pentachlorophenol when incorporated with urea-formaldehyde.

Huber (12) incorporated pentachlorophenol in both urea and phenolic adhesives. He found that 0.6 percent of the oven dry weight of the chips gave good protection in soil block tests with Lenzites trabea.

Brown and Aldon (13) sprayed the preservative on the flakes, rather than mixing it in the adhesive. Using pentachlorophenol at

1.25 percent of the dry chip weight, they produced phenolic resin boards which were very resistant in twelve month exposure tests. Boards produced with urea, using the same method, did not prove durable in the test.

Pentachlorophenol has been the primary preservative used in this type of particle board test. However, others have been used. Sokolova and Timofeeva (14) used sodium fluoride and sodium fluosilicate at 0.5 and 1.0 percent of the dry chip weight. They obtained good protection in this way when the blocks were exposed to <u>Coniophora</u> <u>cerebella</u>.

<u>Criterion of Durability</u>:

There are many criteria for testing the durability of wood. Probably the most accurate method is actual records kept of wood in service. However, the length of time required rules out this method for most practical purposes. The most widely used and accepted method of testing durability is the weight-loss method. This method is outlined in the A.S.T.M. Standard D 1413-61. (15). The above publication includes the method for incorporation of a preservative in the test blocks. A publication by McNabb (16) omits this procedure and gives a good outline of both the soil-block and agar-block method.

Many other methods have been proposed, such as toughness tests, hygroscopicity, crushing strength, and others. A method devised by Brown (17) involves tensile testing of very thin test specimens after exposure to fungi. This method involves much less time (1 to 2 months) in testing than the weight-loss method (4 to 5 months) and Brown obtained good results using this test. Brown has stated that this pro-

cedure should be applicable to particle board testing as well as solid wood[1].

Some of these methods show merit and promise; however, Hartley (18) states, "None of them has enough supporting evidence to justify being substituted for the weight-loss test without further careful study." The weight-loss method measures the loss of wood substance due to metabolic conversion of wood to carbon dioxide and water.

In the weight-loss method, exposure chambers are prepared in most cases with soil and feeder strips. There are many factors which can vary in the preparation of the soil block bottles and if test results are to be compared, these factors must be as uniform as possible. Some of these variable factors which require control are given by Duncan (19) as: 1) soil characteristics, 2) effect of aeration and 3) moisture content of soil relative to its water holding capacity. In tests on these variables, it was found that 1) the soil characteristics had little effect unless extreme soil types were involved, 2) the moisture content of the soil should not exceed 150 percent of its water holding capacity, and 3) to assure aeration, caps should be loosely attached with no liners, or the cap vented with a glass tube.

<u>Wood-Fungi Relationship</u>:

As mentioned earlier, the loss in weight accompanying decay in wood is due to the metabolic conversion of wood to carbon dioxide and water. This conversion is accomplished by enzymatic degradation of cellulose by fungus hyphae moving through the wood substance. The fungus hyphae can move through the wood either through natural openings, such as cell lumens and pits, or through the cell walls.

1. Op. Cit.

The manner in which the hyphae penetrate the cell wall is given by Proctor (20) as, "the secretion of enzymes at the tips of penetrating hyphae, and the total dissolution of the cell wall by enzymatic activity in advance of actual passage through the wall." The hyphae are usually constricted as they move through the cell wall and then expand as they enter the cell cavity.

The actual utilization of the cellulose by the fungi is divided into two types of reactions (21): 1) the extracellular reactions involving the conversion of wood to linear anhydroglucose chains and these in turn to cellobiose, and 2) the intercellular reaction consisting of the conversion of cellobiose to glucose which can be utilized by the hyphae. This last conversion is accomplished by the enzyme β-glucosidase.

The decay of wood usually takes place under conditions of good aeration. However some growth can occur in anaerobic conditions (22). In this case the products are substances such as alcohol and oxalic acid, rather than carbon dioxide.

The production of water can be great enough to sustain the fungus growth if it is well established (18). If evaporation of water is not excessive, the fungus can thrive with no external source of water.

The growth of fungus is slowed down to a great extent in a durable wood or wood treated with a preservative; however, decay does occur slowly in such wood. Lyr (23) has investigated this fact and suggests reasons for its occurrance. He has shown that the extractives pinosylvin-mono-methylether, β-thujaplicin and the chlorophenol preservatives are no longer toxic after oxidation by fungal oxidases such as laccase, tyrosinase, and peroxidase. One or more of these oxidases are present in nearly all fungi which attack wood. Lyr gives the following relative values of the ability of different substances to resist oxidative degration: 1) 5-chlorophenol=100, 2) 4-chlorophenol =95, 3) 3-chlorophenol=86, 4) 2-chlorophenol=60, 5) pinosylvin-monomethylether=20, 6) β-thujaplicin=15.

Lyr also states that, "the tannins of the heartwood strongly inhibit oxidases." This would support the findings that it is the tannins in redwood which are largely responsible for its durability.

PARTICLE BOARD TEST

Wood Source:

Three species of wood were used in this study. The wood was to be as fresh cut as possible and therefore could not be obtained from regular commercial sources. The reason for this was that it was not to be soaked in water before flaking as this could remove extractives. A second reason being that any heat treatment, such as kiln drying, could affect results.

The redwood (*Sequoia sempervirens*) was shipped from California in waterproof paper. The wood was at a very high moisture content and was shipped just after sawing. It was received as rough one inch lumber.

The northern white cedar (*Thuja occidentalis*) was shipped from Northern Michigan in the form of eight to twelve inch diameter posts. This was sawed to one inch lumber at the Forest Products Department sawmill.

The jack pine (*Pinus banksiana*) was cut from the Michigan State University Experimental Forest. This was also sawed into one inch lumber at the Forest Products Department sawmill.

Flake and Board Preparation:

All three species of wood were converted to flakes measuring 1 inch by 0.75 inch by 0.015 inch. Flaking was done on a converted lathe equipped with two knives attached to a steel plate. The flake size was reduced by passing the flakes through a hammermill. A 3/4 inch screen was used on the hammermill for the jack pine and northern cedar. No screen was used in hammermilling the redwood as it is more brittle and was broken up too much with the screen attached.

After reducing the flakes to the proper size, they were air dried to approximately 10 percent moisture content. These flakes were then placed in an equilibrium chamber for twenty-four hours to attain a uniform moisture content of 6 percent. The conditions were 140 degrees Fahrenheit dry bulb and 110 degrees Fahrenheit wet bulb.

The conditioned flakes were then weighed to the correct percentages for each individual board and stored in sealed plastic bags.

All boards contained 275 grams of conditioned flakes and 8 percent adhesive based on the oven dry weight of the flakes.

Two different adhesives were used for the boards; phenol-formaldehyde and urea-formaldehyde. Only the phenol-formaldehyde, due to its moisture resistance, would be suitable for use where decay was important. The urea-formaldehyde was used in a few boards to see how this adhesive might affect results. The adhesive application was accomplished in a rotating drum type mixer. This method not only assured an even application of adhesive, but also blended the mixture of two species. The adhesive was sprayed into the mixer using air pressure and total spraying time was two to three minutes.

In the pressing operation, most variables were held constant and some were varied for a small number of boards. All boards were pressed to a size of 8 inch by 8 inch using 3/8 inch stops on the cauls. The press used was a single opening hydraulic press which has a 200 ton capacity. The press temperature of 325 degrees Fahrenheit and pressure of 500 p.s.i. were maintained for all boards.

Press time was changed on two boards to see if increased heating might affect durability due to its action on extractives.

Tables 1 and 2 show the twenty-three types of boards produced for use in this study; certain of these boards were used in more than one test.

After pressing, the boards were marked and stored in plastic bags before cutting for the exposure tests.

Exposure Procedure:

In preparing the specimens for exposure to the soil block test, several methods for determining the oven dry weight were considered. Actual oven drying was not used due to the question of the effect of heat on the extractives responsible for the woods' durability. Conditioning the blocks to an equilibrium weight is a time consuming procedure and was not used for this reason. The method used was to cut twice the number of specimens required and use half of these to determine the average moisture content of the board. From the moisture content and the weight of the test specimens, the oven dry weight was computed using the following formula:

$$WT_{od} = \frac{WT.gr}{M.C.+1}$$

WT_{od} = Oven dry weight, grams

W_{gr} = Original weight, grams

M.C. = Moisture content at original weight, percent

The exposure chambers were the standard soil block bottles and were prepared as outlined in the A.S.T.M. Standard 1413-61T, with one

exception. This exception was that the feeder strips were inadvertantly cut with the transverse surface on the wide face. It is not felt that this caused any great variation in the results.

The soil used in the bottles was a sandy loam with a water holding capacity of 37.3 percent as determined by A.S.T.M. standards. The pH of the soil was between 6.5 and 6.6 determined with a Beckman pH meter.

The bottles were inoculated with fungus cultures obtained from the U. S. Forest Products Laboratory at Madison, Wisconsin. <u>Lenzites trabea</u> (Madison 617) was the primary fungus used. This fungus is primarily a softwood rotter and is commonly found on wood in service. Two additional series of decay chambers were prepared using <u>Polyporus versicolor</u> (Madison 697). This is considered a hardwood decay agent and was included for comparison.

The sterilized specimens were placed in the decay chambers and these placed in a conditioning room at 80 degrees Fahrenheit and 67 percent relative humidity. The relative humidity dropped to approximately 50 percent for a two week period due to a burned out motor, but the temperature was maintained at 80 ± 1 degrees Fahrenheit throughout the entire test.

The exposure period was twelve weeks and at the end of this time, the specimens were removed, oven dried and weighed to the nearest 0.01 gram. The degree of delamination was determined and is shown in the results.

Results and Discussion:

The results of the particle board decay tests are given in Table 1 and Table 2. Table 1 gives the results for all boards produced using redwood and Table 2 gives results for all boards containing northern white cedar.

The decay-composition relationship of boards 1 through 10 for the redwood is plotted in figure 2, and of boards 1 and 18 through 26, representing the northern white cedar, is plotted in figure 4. On both of these graphs, the weight loss is plotted versus percentage of durable wood present in the board.

Using a mixture of two species of wood in a single board, one of three results should be expected; these three are discussed separately.

In case one, each wood would decay at its normal rate as though the other wood were not present. In this case the plot of weight loss versus percentage of durable wood should be a straight line relationship represented by line "A" on both figures 2 and 4.

In case two, the durable wood could afford some protection to the non-durable wood. In this case the above mentioned curve should concave upward. This would be due to the following: the durable wood would decay at its own rate, but the non-durable wood would decay at a lower rate and move the curve down at all intermediate points.

In case three, no protective action is imparted, but rather, the presence of the non-durable wood provides avenues of travel for the fungus, through the board. In this case, the fungus should travel through the avenues provided by the non-durable wood and branch out into the durable wood. These mycelium branches could utilize the durable wood as food substance until the toxic extractives stopped

their growth. In case three the percentage of decay of durable wood should decrease as the thickness of durable wood that the mycelium must pass through increases. For the 100 percent redwood board the decay would be limited to the outer shell of the particle board. In the boards manufactured partially of redwood, this surface of vulnerability is greatly increased.

The shape of the curve in this case should be concave downward. The reasoning for this is analagous to that for the opposite case. The non-durable wood should decay at its own rate, but the durable wood would decay faster and raise the intermediate points.

The shape of the curve for both species would seem to conform to case three. The curve for northern white cedar starts at a lower point; however, the upper portion of the curve is level, rather than the lower portion. This fact would still indicate that for the particular boards tested, case three would seem to be true.

The columns giving delamination data indicate the degree of delamination after testing and subsequent drying. The rating system, as stated on page 17, Table 1, was taken from Forest Products Laboratory Bulletin No. 2196. In this report they stated, "Severe delamination was not necessarily associated with high weight loss nor was the lack of delamination closely correlated with a low weight loss." In the present study, this was not found to be necessarily true. With the exception of the 100 percent redwood board produced with urea formaldehyde, the degree of delamination would seem to be correlated with weight loss. Figure 5 illustrates this factor for representative samples.

Table 1. Board preparation data and test results for redwood particle board.

Group number	Board Type % redwood	% pine	Press time minutes	Fungus	Adhesive	Delamination (1)	Weight loss %	Density grams/cc(2)
1	0	100	9	Lenzites trabea	Phenol formaldehyde	4	30.0	0.79
2	5	95	"	"	"	4	26.3	0.87
3	10	90	"	"	"	4	30.2	0.80
4	15	85	"	"	"	4	23.7	0.81
* 5	20	80	"	"	"	4-5	32.3	0.61
6	25	75	"	"	"	4	26.5	0.66
7	35	65	"	"	"	4	26.7	0.68
8	50	50	"	"	"	4	20.7	0.66
9	75	25	"	"	"	4	17.9	0.57
10	100	0	"	"	"	1	4.1	0.85
11	25	75	"	"	Urea formaldehyde	5	36.4	0.87
12	100	0	"	"	"	3-4	4.1	0.82
13	25	75	15	"	Phenol formaldehyde	4	25.3	0.87
14	100	0	15	"	"	1	3.9	0.87
15	25	75	9	Polyporous versicolor	"	2	15.3	0.66
*16	100	0	"	"	"	1	0.8	0.85
**17	25	75	"	Lenzites trabea	"	4	22.9	0.66

(1) Numerical delamination ratio scheme was: 5- Total delamination of block; 4- up to 1/2 of block delaminated, with remainder intact but separable with finger pressure; 3- no delamination but intact, block separable; 2- up to 1/2 delamination with remainder not separable; and 1- no delamination and block not separable.

(2) Based on 10 percent moisture content.

* Results based on four samples.

** Oven dried 41 hours before testing.

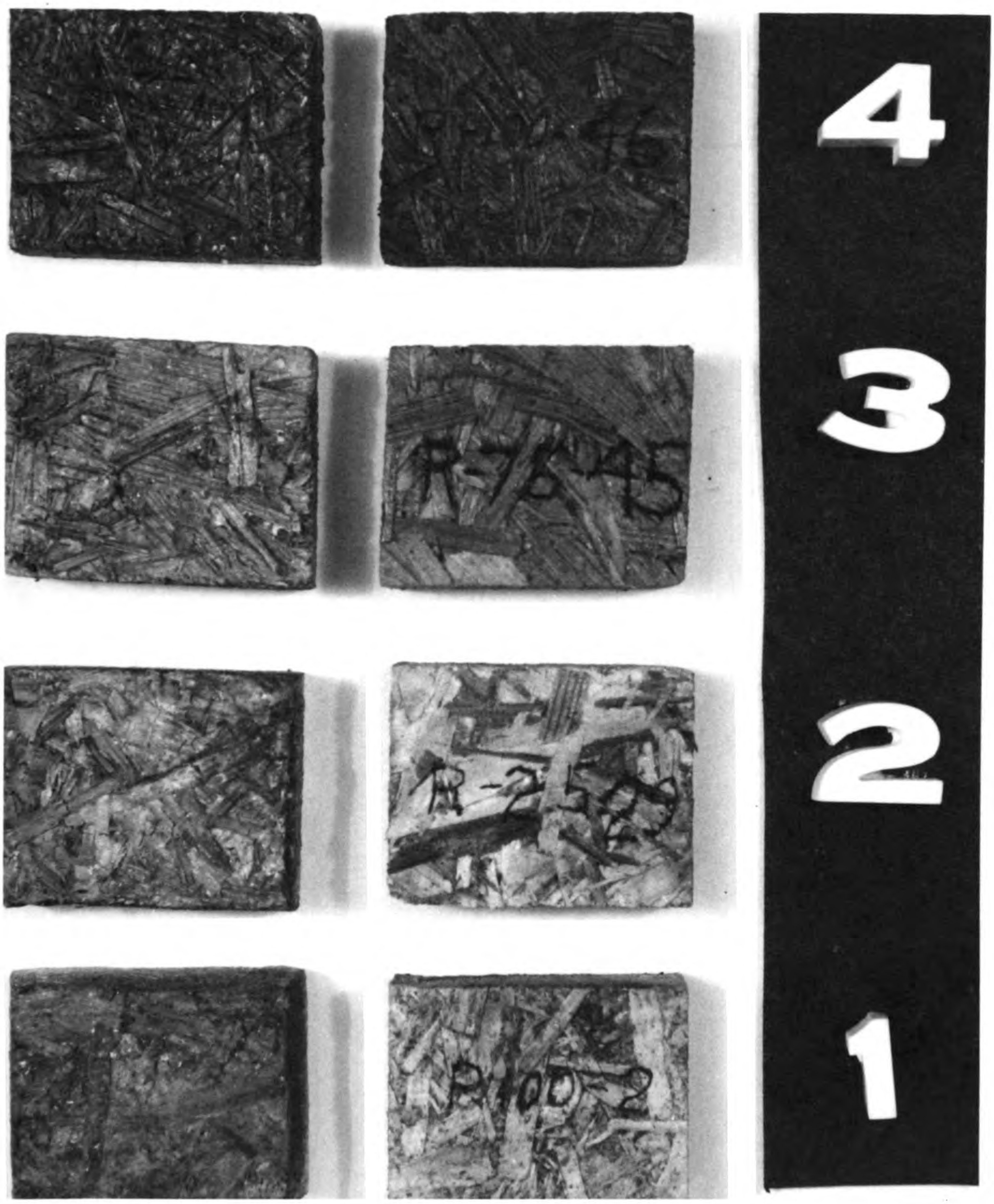


Figure 1. Appearance of decayed redwood particle board; 1) 100% pine, 2) 25% redwood, 3) 75% redwood, and 4) 100% redwood. Boards at left illustrate surface in contact with feeder strips, upper face shown at right.

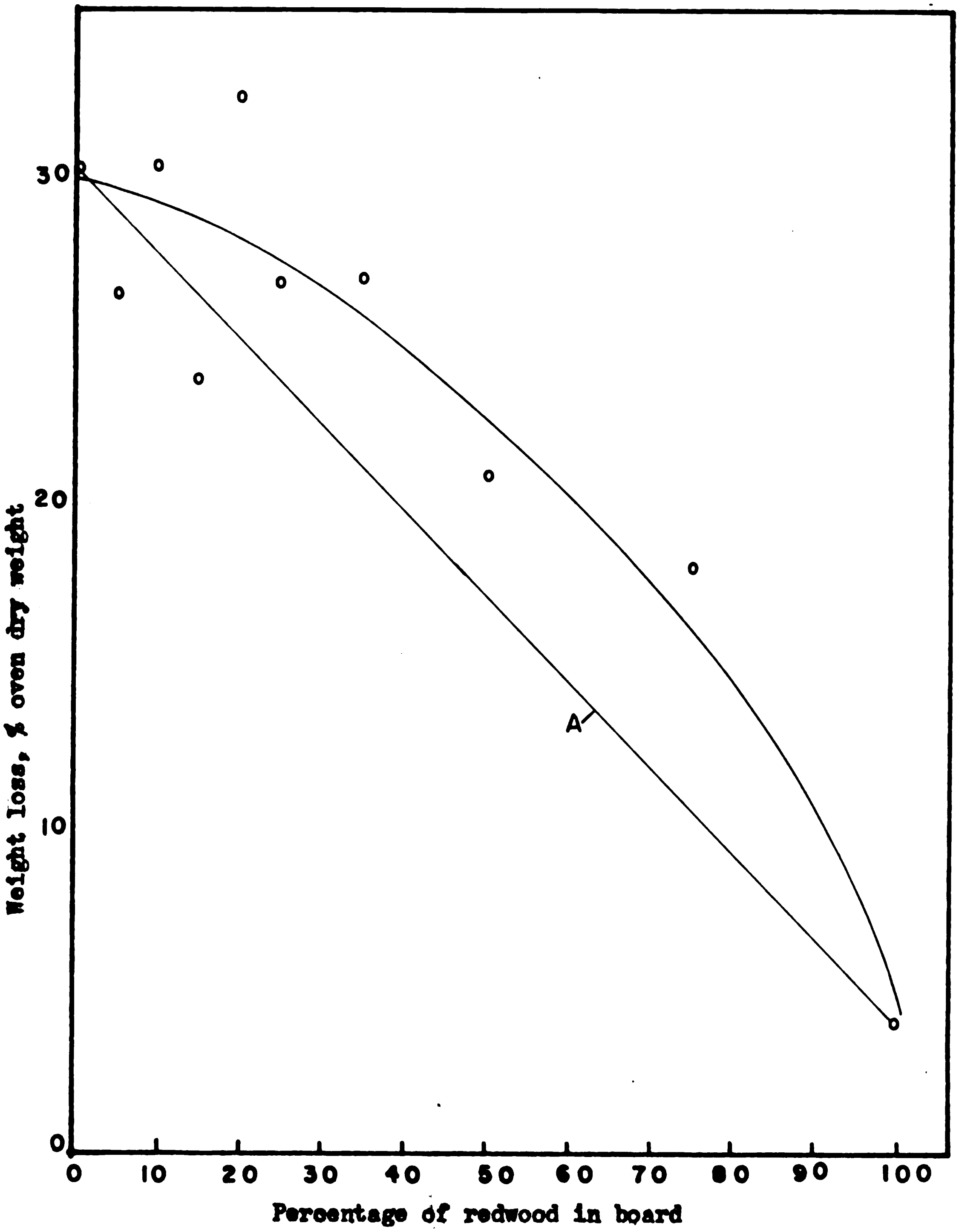


Figure 2. Weight loss versus redwood content in particle board.

Table 2. Board preparation data and test results for northern white cedar particle board.

Group number	Board Type % cedar	Board Type % pine	Press time minutes	Fungus	Adhesive	Delamination (1)	Weight loss %	Density grams/cc (2)
1	0	100	9	Lenzites trabea	Phenol formaldehyde	4	30.0	0.79
18	5	95	"	"	"	4	20.8	0.83
19	10	90	"	"	"	4	22.7	0.84
20	15	85	"	"	"	4	22.5	0.73
21	20	80	"	"	"	2	10.3	0.75
22	25	75	"	"	"	4	21.8	0.81
23	35	65	"	"	"	4	24.0	0.76
24	50	50	"	"	"	4	18.3	0.77
25	75	25	"	"	"	2	9.6	0.81
26	100	0	"	"	"	2	6.6	0.79

(1) See footnote page 17.

(2) Based on 10 percent moisture content.

Figure 3. Appearance of decayed northern white cedar particle board; 1) 100% pine, 2) 25% cedar, 3) 75% cedar, and 4) 100% cedar. Boards at left illustrate surface in contact with feeder strips, upper face shown at right.

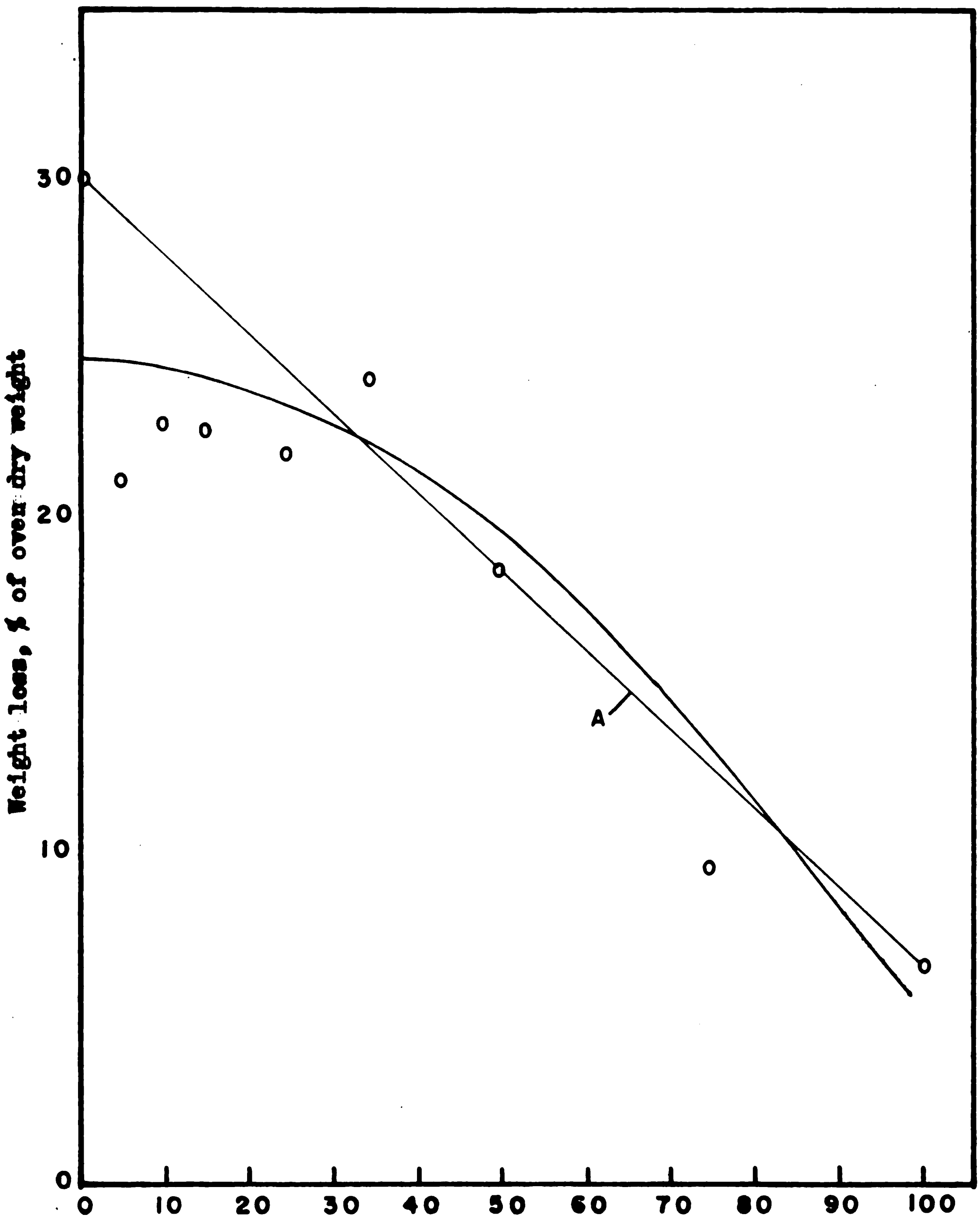


Figure 4. Weight loss versus northern white cedar content in particle board.

Specimen groups 13, 14, and 17 were added to this study to see what effect increased heating might have on durability. Specimen groups 6, 13, and 17 were all produced with 25 percent redwood and 75 percent pine. The amount of heat applied to these three groups is quite different as shown in table 1, but the weight loss data are not appreciably different. Specimen groups 10 and 14 also have the same makeup, but different amounts of heat application. Here again, the weight loss is not changed by additional heat.

Specimen groups 11 and 12 were produced with urea-formaldehyde, which is not water resistant. In the 25% redwood group, the decay loss increased and the boards were badly delaminated. The 100 percent redwood board was not delaminated when removed from the exposure chambers, but upon drying, delamination occurred. The weight loss of this board was not increased due to the use of urea-formaldehyde adhesive.

Solid blocks of both redwood and northern white cedar were tested for durability under exactly the same conditions as the particle board specimens. The weight loss for the solid redwood blocks was 11.6 percent, whereas the weight loss for the solid northern white cedar blocks was 0.9 percent.

In comparing the decay losses of solid blocks with the 100 percent durable wood particle boards, we find the results are not well correlated. Redwood particle board lost 4.1 percent of its weight, but the solid redwood lost 11.6 percent. The most obvious factor causing this reduction would seem to be the presence of the phenol-formaldehyde adhesive which is toxic. However the 100 percent redwood board manufactured with urea-formaldehyde adhesive lost no more weight than the 100

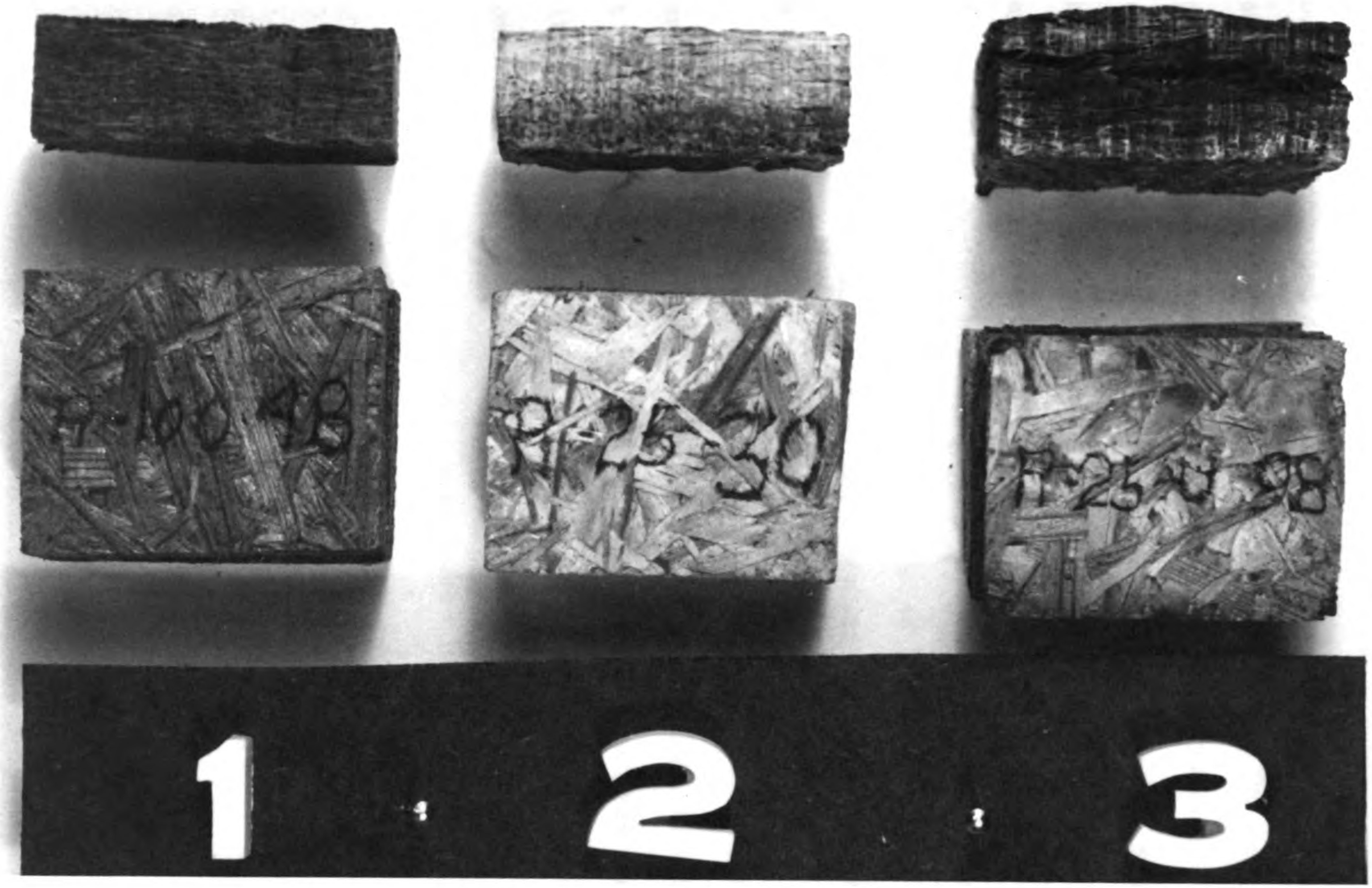


Figure 5. Degree of delamination in redwood particle boards. 1) 100% redwood, phenol-formaldehyde adhesive, 2) 25% redwood, phenol-formaldehyde adhesive, 3) 25% redwood, urea-formaldehyde adhesive.

percent redwood board manufactured with the phenol-formaldehyde.

Another factor which could account for the increased durability would be the increased density of the particle board over the solid wood. The density increased from 0.40 gram $cm.^{-3}$ to 0.76 gram cm^{-3} (oven dry basis) for redwood and this could explain the variation. Density is a questionable criterion of durability; however, Southam and Ehrlich (24) concluded that, "For a single species of wood there may be a tendency toward greater initial decay resistance in wood of high specific gravity, but this tendency is nullified and may even be reversed as decay progresses, and so is of little practical value." The first half of this statement could explain the results obtained in this study.

The decrease in durability of the northern white cedar particle board compared to the solid block could not be explained in this way. It is possible that some toxic component of the extractives reacted with the phenol-formaldehyde and was lost in this way. There is no comparable board produced with urea-formaldehyde and therefore it is difficult to draw conclusions in this case.

VENEER TEST

Procedure:

This test was designed to determine if a durable wood could protect a thin layer of non-durable wood in close contact with it.

Thin veneers of southern yellow pine sapwood were cut at varying thickness measurements. The thickness began at approximately 0.005 inch and was increased by 0.010 inch intervals to a maximum of 0.055 inch. These veneers were trimmed to 0.75 inch by 1 inch. The oven dry weight of the veneers was determined by the same method used for the particle board specimens. The weight was determined to the nearest 0.0001 gram as the veneers were of very low weight.

These veneers were fastened to the top of a small block of redwood of the same dimension as the veneer. The veneers had to be firmly attached so they would remain in close contact. This was accomplished by having the veneers at a high moisture content before fastening them down on the redwood block. In this way they would not swell in the moist decay chambers and buckle away from the redwood block. The veneers were held down with two nichrome wires placed and tightened around the entire assembly. It was felt that the nichrome wire was so inert that it could have no effect on the fungus growth. Figure 6 shows the completed test assembly and the materials going into it.

Five assemblies of each veneer thickness were exposed in standard soil block bottles, to the fungus Lenzites trabea. The

specimens were exposed with the non-durable veneer resting directly on the feeder strips in the soil block bottles. The same soil and conditions were used for these exposure chambers as in the particle board tests.

A control group of five veneers with no redwood contact were also tested. These veneers were placed directly on the feeder strips and held down with squares of heavy window glass.

The specimens were removed from the chambers at the end of four weeks. The pine veneers were carefully removed and oven dried. Some of the thinner veneers had to be oven dried in individual containers so that no particles would be lost. The specimens were then weighed to the same accuracy as prior to test. Weighing was done using closed weighing bottles so that no moisture could be picked up and affect results.

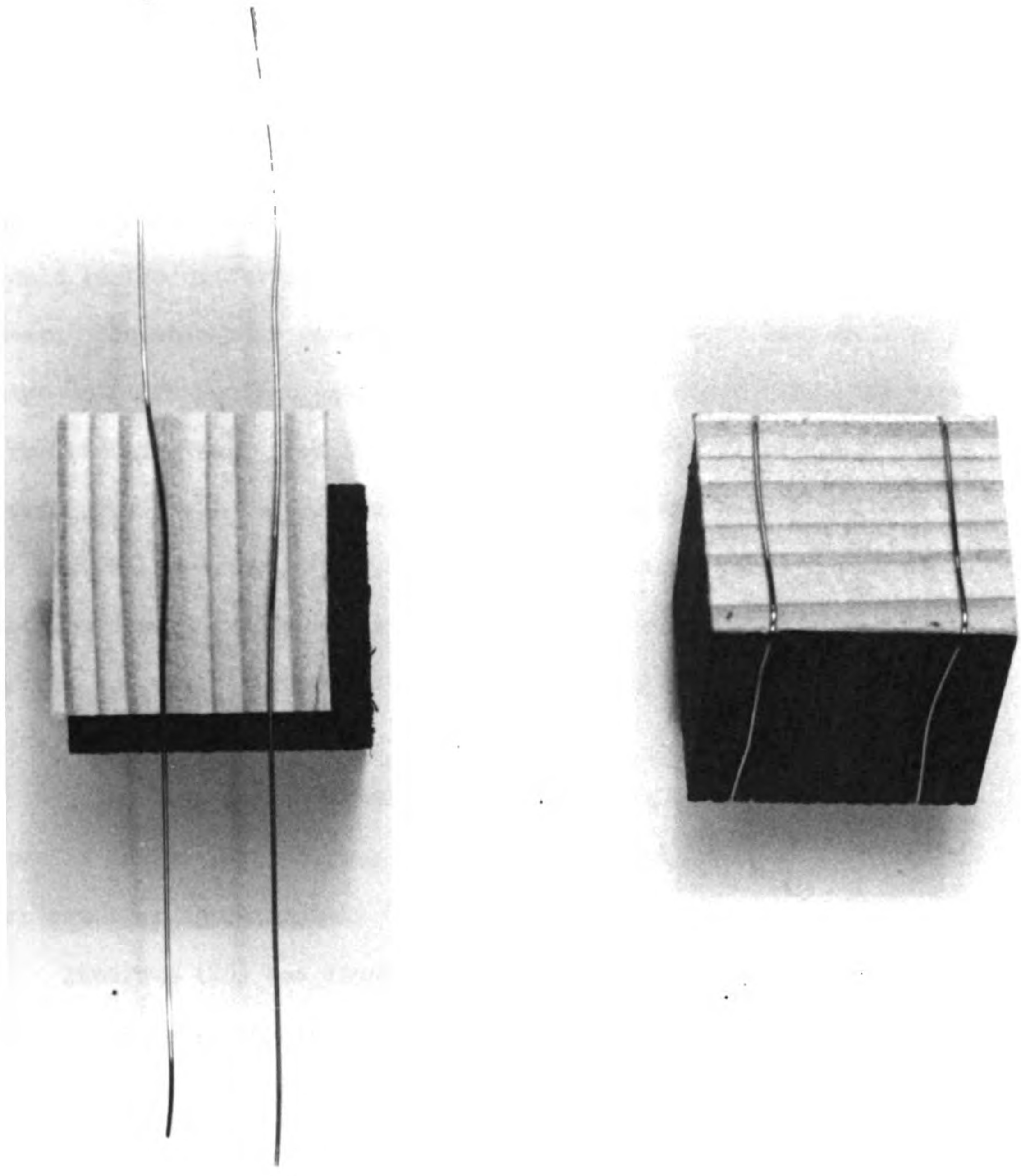


Figure 6. Method of assembly and complete "Veneer Test" Assembly.

Results and Discussion:

From the results of the veneer test, it is obvious that the redwood imparted a protective action to the thin pine veneers. This fact is not entirely in agreement with results obtained from the particle board test. A possible reason for these differences could be the difference in moisture conditions of the test specimens. The thin pine veneers and redwood blocks were kept at a very high moisture content prior to exposure. This was to keep the veneer from buckling away from the redwood blocks in the moist decay chambers. The completed assemblies, at this very wet condition, were then sterilized for 20 minutes prior to exposure. This period of heating should produce considerable movement of steam and carry some of the hot water soluble extractives from the redwood through the pine veneer.

At no time during manufacture and testing were the mixtures of species in the particle board subjected to heat while at a moisture content over approximately 6 percent.

Anderson (25) has found that when redwood lumber dries, water solubles are carried to the outer surface of the lumber. He states that, "As the moisture evaporates from the surface, it leaves a heavy deposition of water solubles at and near the surface." The above statement and the fact that the completed assemblies were above the fiber saturation point could explain the increased durability of the pine veneers attached to the redwood blocks.

Table 3. Test results for veneer test.

Veneer thickness, inches	Wt. loss, %	Wt. loss, grams
0.007	15.8	0.0060
0.014	11.2	0.0074
0.026	13.0	0.0191
0.037	4.9	0.0116
0.046	8.0	0.0215
0.053	8.3	0.0260
0.013*	64.1	0.0417

* Control, no redwood block

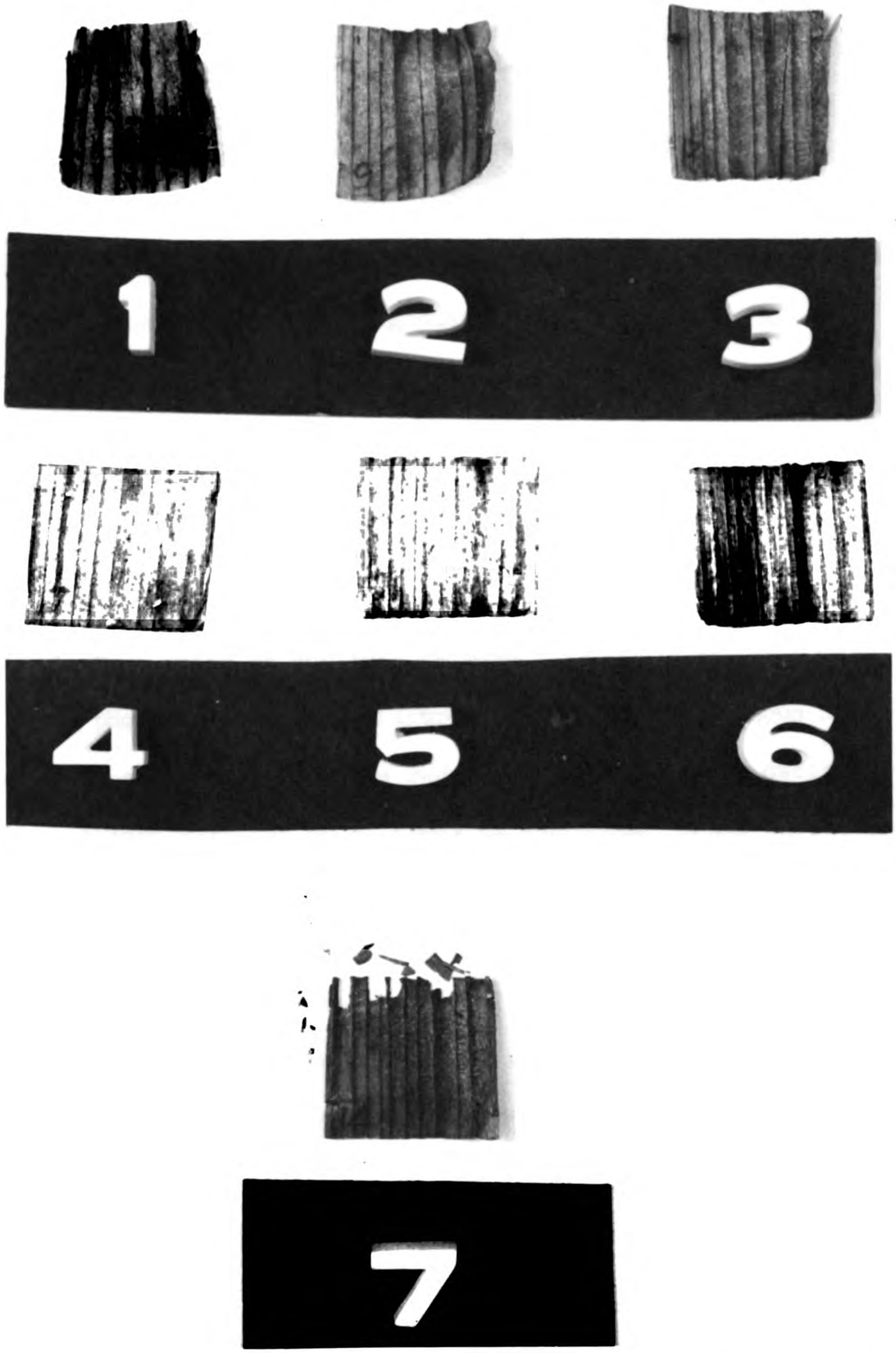


Figure 7. Appearance of pine veneers after exposure to <u>Lenzites trabea</u>. Thickness of veneers was: 1) 0.007 inch, 2) 0.014 inch, 3) 0.026 inch, 4) 0.037 inch, 5) 0.046 inch, and 6) 0.053 inch. Number 7 shows extreme of decay present in veneer of 0.026 inch thickness.

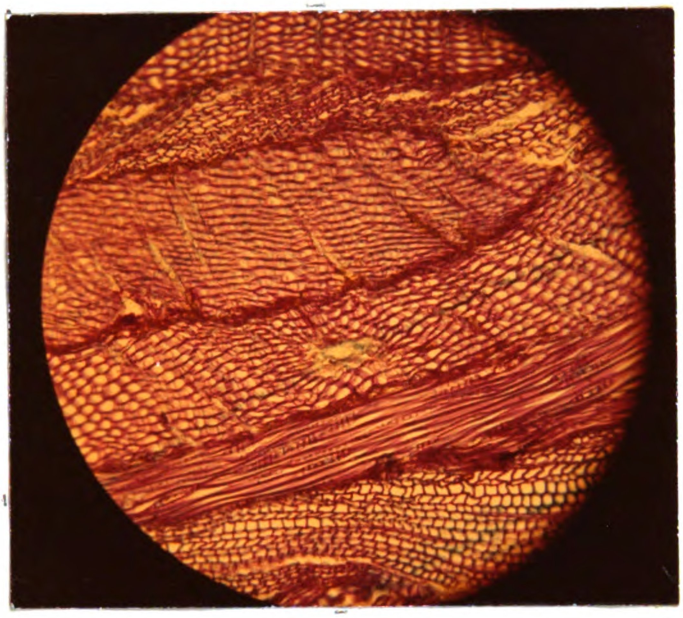
MICROSCOPIC EXAMINATION

Microscopic slides were made of various redwood boards used in this study to show board makeup and location of decay. Color photomicrographs were taken of the 25 percent redwood particle board before and after exposure to decay organisms.

Figure 8 illustrates the cross section of the 25 percent board prior to decay tests. This block was prepared for sectioning by imbedding the particle board in butyl-methacrylate; the procedure followed is given in a publication by Rohm & Haas Company (26). Sectioning was done on a sliding microtome and the slide was stained with safranin-fast green as outlined in Sass (27).

The photomicrographs in Figure 9 illustrate the fungus hyphae present in a board of the same redwood percentage after decay tests. These sections were cut on a freezing microtome using carbon dioxide under pressure to freeze the block while cutting. These sections were stained with safranin and picroanaline blue as outlined in Cartwright and Findlay (22). The decayed sections were cut from a position as close to the center of the test block as possible.

Sections were also cut from the center of the 100 percent redwood particle board after exposure in the decay test. No fungus hyphae were observed in these sections. The fact that hyphae were found in the center of the 25 percent redwood board would seem to substantiate the theory that the pine allows entrance of the fungus into the center of the board. Numerous hyphae were found in sections made from redwood flakes removed from the center of the 25 percent redwood board. This gives evidence that once the fungus gains entrance through the "avenues of travel" furnished by the pine, it can attack the redwood in the center of the block. This means the redwood flakes adjacent to pine flakes in the center of the 25 percent redwood board are as susceptible to decay as the redwood flakes on the exterior of the 100 percent redwood board. Hyphae were found in the surface flakes of the 100 percent redwood board.



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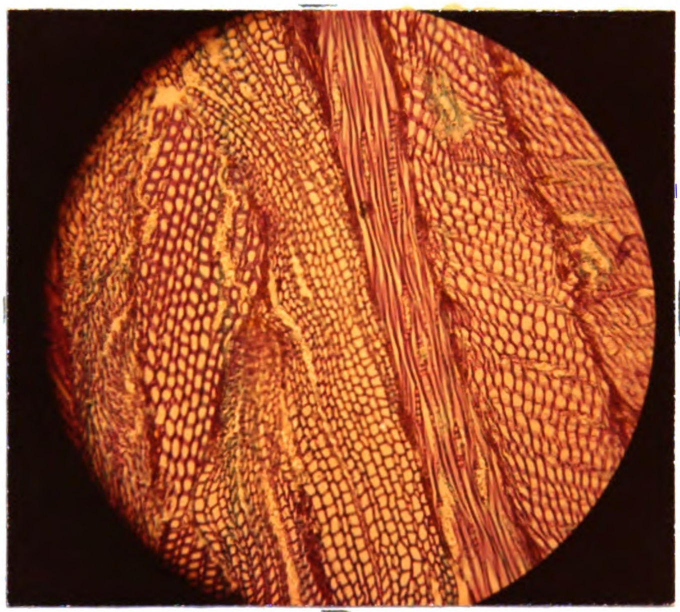

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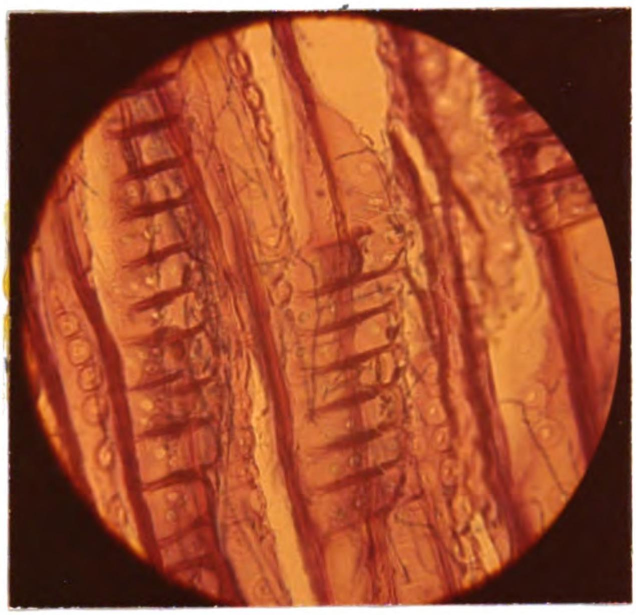
Figure 8. Photomicrographs of 25 percent redwood particle board prior to decay tests.



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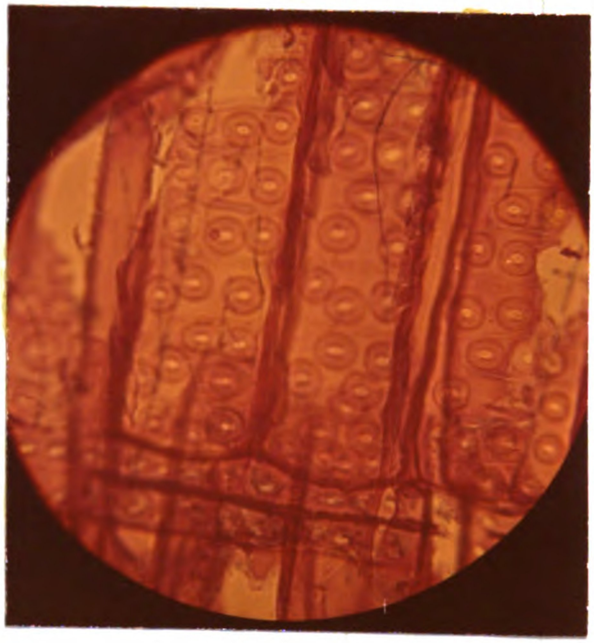

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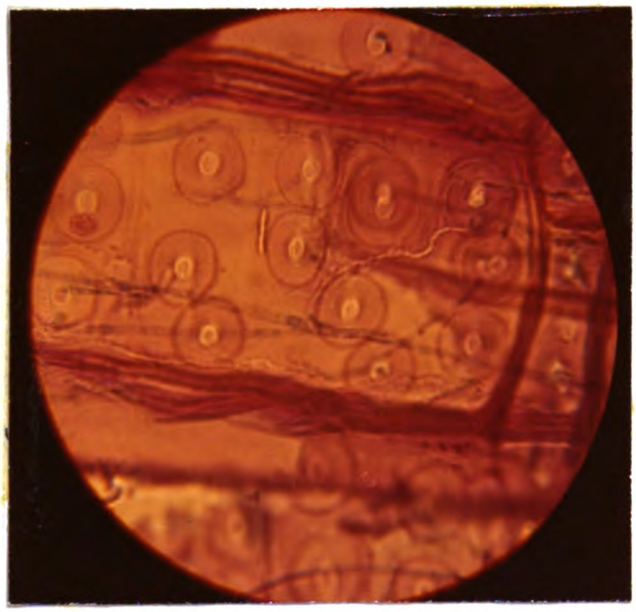

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Figure 9. Photomicrographs of 25 percent redwood particle board after decay tests, showing fungus hyphae.

CONCLUSIONS

From the results of this study, the principle of protecting a non-durable wood with a durable species does not seem feasible with the manufacturing methods used.

The results of the veneer test illustrate that the redwood can protect a non-durable species under suitable conditions. Whether these conditions could be applied to particle board manufacture cannot be answered in this paper.

The boards manufactured with urea-formaldehyde adhesive demonstrate that even a durable species particle board is subject to severe delamination with this adhesive.

The different degrees of heat had no effect on the durability of the boards produced. From these results it would seem that the heat used in the normal production of particle board does not impair the decay resisting effectiveness of the extractives in redwood.

Increasing the density of the redwood in particle board as compared to solid wood increased its durability considerably. Whether this increase is only in the initial stages of decay cannot be told from the data.

RECOMMENDATIONS FOR FURTHER STUDY

This study was undertaken to determine whether a durable species could protect a non-durable species from decay. With the methods used in the production of the particle board tested, it would seem that no protective action was imparted.

A primary factor deserving more attention is the movement of extractives through the board. If the board were soaked in water, some of the extractives might leach into the non-durable species and protect it in this way. Another possibility is that if the boards were pressed at a high moisture content, the increased steam during pressing might carry extractives through the entire board.

Density might also be a factor affecting the durability of a board produced in this way. If the flakes were brought into closer contact, the durable wood might prove more effective.

BIBLIOGRAPHY

1. Anon. 1945. Redwood. The Institute of Paper Chemistry Research Bulletin.

2. Wise, L. E. 1944. Wood Chemistry. Reinhold Publishing Corporation, New York.

3. Hillis, W. E. 1962. Wood Extractives. Academic Press, New York and London.

4. Gripenberg, J. 1949. The Constituents of the (Heart) Wood of Thuja occidentalis L. Acta Chemica Scandinavica, Copenhagen 3 (7). From Forestry Abstracts 1949-50. 11 (pp. 484)

5. Scheffer, T. C. and Hopp, H. 1949. Decay Resistance of Black Locust Heartwood. U.S.D.A. Technical Bulletin 984.

6. Tarkow, H. and Krueger, J. 1961. Distribution of Hot Water Soluble Material in Cell Walls and Cavities of Redwood. For. Prod.Jour. 11 (5).

7. Anderson, A. B., Duncan, C. G. and Scheffer, T. C. 1962. Effect of Drying Conditions on Durability of California Redwood. For. Prod.Jour. 12 (7).

8. Hann, R. A., Black, J. M. and Blomquist, R. F. 1962. How Durable is a Particle Board? For. Prod. Jour. 12 (12).

9. Clark, J. W. 1960. Decay Resistance of Experimental and Commercial Particle Board. U. S. For. Prod. Lab. Report 2196.

10. Klauditz, W. and Stolley, I. 1954. Development and Manufacture of Chipboards Resistant to Fungi and Termites. Holz. Roh-u. Werkstoff 12 (5). From Forestry Abstracts 1955. 16 (pp 292).

11. Narayanamurti, D., Prasab, B. N., and George, J. 1961. Protection of Chipboard from Fungi and Termites. Norsk. Skogind. 15 (9). From Forestry Abstracts 1962. 23 (pp. 336)

12. Huber, H. A. 1958. Preservation of Particle Board and Hardboard with Pentachlorophenol. For. Prod. Jour. 8 (12).

13. Brown, G. E. and Aldon, H. M. 1960. Protection From Termites: Penta for Particle Boards. For. Prod. Jour. 10 (9).

14. Sokolova, T. E. and Timofeeva, O. G. 1959. Biological Protection of Wood Chip Panels. Stroitelnye Materialy 5 (10). From Forestry Abstracts 1960. 21 (pp. 675).

15. Anon:________ American Society for Testing and Materials. 1956. Method of Testing Wood Preservatives by Laboratory Soil-Block Cultures. A.S.T.M.designation: D1413-61.

16. McNabb, H. S. 1958. Procedures of Laboratory Studies on Wood Decay Resistance. Proc. Iowa Academy of Science 65:150-159.

17. Brown, F. L. 1963. A Tensile Strength Test for Comparative Evaluation of Wood Preservatives. For. Prod. Jour. 13 (9).

18. Hartley, C. 1958. Evaluation of Wood Decay in Experimental Work. U. S. For Prod. Lab. Report 2119.

19. Duncan, C. G. 1958. Studies of the Methodology of Soil-Block Testing. For. Prod. Lab. Report 2114.

20. Proctor, P. 1941. Penetration of the Walls of Wood Cells by the Hyphae of Wood-destroying Fungi. Yale School of Forestry Bull. 47.

21. Cowling, E.B. 1958. A review of Literature on the Enzymatic Degradation of Cellulose and Wood. For. Prod. Lab. Report 2116.

22. Cartwright, K. St. G. and Findlay, W. P. K. 1958. Decay of Timber and its Prevention. Her Majesty's Stationery Office, London.

23. Lyr, H. 1962. Detoxification of Heartwood Toxins and Chlorophenols by Higher Fungi. Nature 195.

24. Brown, H. P., Panshin, A. J., and Forsaith, C.C. 1949. Textbook of Wood Technology. Vol. 1. McGraw-Hill Book Company, Inc. New York, Toronto and London.

25. Anderson, A. B. 1961. The Influence of Extractives on Tree Properties. 1. California Redwood (Sequoia Sempervirens). Jour. Institute of Wood Science. 8.

26. Anon:____ Embedding Specimens in Methacrylate Resins. Rohm & Haas Company, Philadelphia.

27. Sass, J. E. 1961. Botanical Microtechnique. The Iowa State University Press, Ames, Iowa.

28. Colley, R. H. 1953. The Evaluation of Wood Preservatives. Bell Telephone System, Technical Publication Monograph 2118.