FABRICATION AND EVALUATION OF "OBECHE" PARTICLEBOARD AS BUILDING MATERIAL FOR NIGERIAN HOUSING

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ABSTRACT

Fabrication and Evaluation of "Obeche" Particleboard as Building Material for Nigerian Housing.

The purpose of this study was to establish that particleboard can be manufactured from a single Nigerian timber species such as Obeche. It was also decided to treat such particleboard with preservative and determine the threshold values as well as the effect of density of the respective boards on the preservative efficiency

On the overall 12 boards were made, six at a nominal specific gravity of .45 and the other six at a nominal specific gravity of .60. Six levels of preservative treatments (1% to 0%) were employed. The preservative used was sodium pentachlorophenate. The decay test was the soil-block method employing two fungi, *Lenzites trabea* and *Polyporus versicolor*.

The housing situation in Nigeria was reviewed with particular emphasis on local building and construction materials and practices and their shortcomings. Avenues for improvement were suggested.

It was concluded that particleboard exceeding the commercial standard can be manufactured from a single Nigerian timber species such as Obeche. Such boards can be treated with preservative to render it resistance to fungal attack. The specific gravity of the individual boards did not have any significant effect on the preservative efficiency as measured by percentage weight loss in a soil-block test.

FABRICATION AND EVALUATION OF "OBECHE" PARTICLEBOARD AS BUILDING MATERIAL FOR NIGERIAN HOUSING

By

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INTRODUCTION

The use of solid wood in housing per unit in the world is on the decline (48). The amount of wood in each unit in general is on the increase. This is because of the general tendency towards building dwellings with an increasing number of rooms. Another reason is the replacement of solid wood by wood sheet materials or reconstituted wood namely plywood, fiberboard, hardboard and particleboard.

Particleboard has been described by several workers:

Suchsland (44) described it as "--- consisting of small wooden elements randomly distributed and oriented, arranged in layers and glued together to form a composite board ---".

FAO (23) defines particleboard as a sheet material manufactured from small pieces of wood or other lignocellulosic material (chips, flakes, splinters, shives, strands, etc.) agglomerated by use of organic binder together with one or more of the following agents; heat, pressure, moisture, a catalyst, etc.

The British Standard (14) No. 1811 describes particleboard as boards made from particles of wood and/or other lignocellulosic materials bonded with synthetic resins and/or other organic binders.

The particleboard industry has grown steadily since its inception in the early 1950's to one of the major Forest Products industries in the world. The world production figures for 1966 - 1973 are indicated in Table 1. This bears out the steady rate of growth; 16.3% for

Western Europe and 9.1% for the United States, the two major producers for the year 1972-73.

Table 1. World Particleboard Production Per The Major Producers For The Period 1966 to 1973.

YEAR	QUANTITY PER MAJOR PRODUCER (x 1000 cubic meters)			
	UNITED STATES	CANADA	WESTERN EUROPE	JAPAN
1966	2012	-	-	-
1967	2157	-	6235	-
1968	2650	-	7566	-
1969	3163	-	8990	-
1970	3520	-	10326	-
1971	4238.783	-	12142	280
1972	5530	508.453	14243	317
1973	6032	562.144	16560	350

Source: FESYP Reports 1973.

The principal particleboard consumers in the United States are the building industry, mobile homes manufacturers and the furniture industry. Floor underlayment consumes about one-third of the total United States production. The other two-thirds are taken up by the furniture industry.

Ellefson (21) estimated the per house consumption as 115 square feet for the North Central Region of the United States.

Figures available for Western European consumption of particleboard show that the building industry alone takes about 47% of the production. This breaks down to 16% for walls and ceilings, 7.61% for roofs while about 7% goes into floors. The built-in-furniture industry uses about 11.7% and 4% goes into miscellaneous uses. Forty-eight percent are used by the furniture industry. (FESYP 1973 - [3]). Other users are railways, motor cars, containers, etc.; shipbuilding, packaging and other cabinetries.

The full potential of particleboard utilization in housing has not been reached yet in the United States. Virtually all the application in this country are in non-structural categories. Also the limitations of urea-formaldehyde resin, used in most United States particleboards further restrict applications to less severe places of exposure. This is inspite of availability of phenolic resins, due to cost factors, its use is limited. A major reason for the limited use of particleboard as a structural material is the abundance of softwood plywood supply in the United States. Particleboard could not compete with plywood pricewise and in structural qualities. The opposite is true for Western Europe where the firm of Otto Kreibaum, particle board manufacturers of Lauenstein, West Germany errected a house entirely of particleboard that are still in satisfactory condition after 20 years.

Very little particleboard is manufactured and used in the tropical areas of the world. The severe exposure conditions in these areas would make preservative treatment of the boards absolutely necessary, particularly if used in housing construction. On the other hand, properly treated particleboard, produced locally might be an economically attractive building material in many of the relatively underdeveloped and developing nations of the world.

OBJECTIVE

Particleboard is a flexible wood sheet material with very obvious advantages of uniformity in physical and strength properties. It is less demanding on raw material requirements than say plywood or lumber. It can be made from as varied raw materials as round logs to shavings. The properties of the resultant boards can be controlled to a considerable extent by process variables.

The technology for particleboard production is well developed and world wide. Turn key plants are available at reasonable cost and each plant can be adapted to suit any climatic condition.

Due to its inherent properties of variation in sizes and thicknesses; particleboard has a great potential as a building material. This is already being shown in West European countries where about 46.6% of the total particleboard production goes into the building industry, (3).

Particleboard may be used in the tropics if it can be protected from fungi and termite attacks. This factor of biological attack has considerably slowed down the development of wood as a potential building material of great magnitude.

Thus the objectives of this experiment are twofold: First, to demonstrate that a particleboard of acceptable properties can be made from a common Nigerian timber species. Second, to try to establish threshold values of preservative treatment against fungi attack using Sodium Pentachlorophenate.

In addition it is my hope that experiments of this kind will encourage further work in this important area and will help influence the attitudes of Government officials who develop housing policy in Nigeria.

HISTORY OF PARTICLEBOARD

Wood has many advantages as well as disadvantages in construction. The limitation on design imposed by solid timber, obviously led craftsmen to think of overcoming these.

One of the earliest ways of producing large panels relatively stable and free from defects was by making a form of plywood.

The early Egyptians cut veneers and glued them together. However, they did not know the principle of cross lamination to which modern plywood owes its qualities.

This form of panel construction was well known and used to a limited extent by European cabinet makers of the eighteenth century. It was not until the late nineteenth century that commercial plywood as it is known today, became available.

This development simplified the manufacture and the design of furniture by providing large almost defect free panels in form of blockboards or lumber core boards.

The invention of hardboard and particleboard resulted from a different principle. This was that, it was possible to break down wood substance and reconstitute it. The break down presented no initial problems as it followed the precedence of paper making.

With the introduction of wood working machinery and the inevitable large quantities of wood residue, the possibility of binding these particles together must have assumed greater importance. The wastes were in form of off-cuts, shavings and sawdust.

In 1905 the United States Patent Office issued a basic patent to Henry Watson for the invention of particleboard as it is known today. Most of the then known adhesives - animal or casein glue were unsuitable for the manufacture of particleboard. Only the invention of thermo-setting synthetic resin in the late 1920's and the early 1930's solved the binder problems.

Experimental boards were first made by mixing wood particles with a synthetic resin. This mixture was then spread on a flat plate, then heat and pressure were applied.

In Europe the first commercial plant was operated in Germany in 1941. But large scale industrial manufacture of what is now particleboard became established after the Second World War. In the United Kingdom, particleboard manufacture was attempted in about 1946 to 1947. Shavings were utilized as raw material to produce a single layered board type. The process was crude and the boards were too heavy and not of particularly good qualities. In the United States, the particleboard industry did not start until the 1950's.

For many years in the United Kingdom the entire particleboard production was used for various purposes in the building industry. The opposite is true in the case of Germany. Here, it was developed from its latent stage owing to the war by the furniture manufacturers. They soon turned from the use of mill residue to round wood. This resulted in the development of boards of superior quality.

The poineer firms were: Behr of Wendlingen, Kreibaum of Lauenstein, Baehre of Springe together with engineer Fahrni of Switzerland. They were foremost in the development of this board product.

Owing to economic pressure, particularly in the United States, roundwood has now become too expensive a raw material for particleboard. The basic raw material in the United States today is softwood planer shavings. However particleboards are also made from flakes, slivers, sawdust particles and fibers. The term particleboard has become a generic name for all these similar board products.

NIGERIAN HOUSING

Resources

Geographically Nigeria is situated in the hot humid tropics, on the West African coast. It occupies a land area of about 983,000 square kilometers, bounded by latitudes 4° and 14° North and longitudes 2° and 15° West. The terrain is relatively flat and supports a wide variety of vegetation types. Its human population of over 70 million has greatly altered this natural vegetation. So much so that four-fifths of the land area bears savanna while one-fifth is comprised of high forest, plantation and a mosaic of farm and forests.

A large proportion of the Nigerian population cook their meals on open fire.

The estimated per capita Gross National Product of Nigeria was 120 dollars for 1973 (5).

About 96,060 square kilometers of the land area are permanently devoted to forestry, i.e. about 10% of the total land area. Only 1% of the total land area consists of man-made forests. Savanna occupies about 75,000 square kilometers i.e. 7.6% of this, while forests cover about 20,000 square kilometers i.e. 2.04%. The swamp and montane vegetation occupies 0.36% of this forestry estate (4).

The forest estate has supported a bouyant export trade in logs and lumber while also meeting the increasing domestic demand. The details of the export trade for 1962 to 1972 are shown in Table 2. As the standard of living of the people rose there was a steady decrease of the exported logs and lumber, quantitatively. This was partly due to increased domestic demands. This increase in domestic demand has resulted in the use of a wider range of species and low grade timber otherwise not acceptable on the foreign market. The natural forest is rich in tree species composition.

The natural forest is steadily being converted to timber crop plantation at the average rate of 10,000 hectares per year. With this, the use of smaller sized logs and thinnings will become more prominent.

The existing sawmills of about 300 in number are small and inefficient in both conversion and management. They are geared to handling large sized logs. There is a high rate of wastage in raw material in these mills. There are at present four large plywood mills in existence and two more are being proposed.

The thinnings from the plantation and the waste from the inefficiently run sawmills as well as the plywood waste could serve as raw material for particleboard production.

Technically there has been some pioneer work done on wood as a building material. Some of the old colonial houses of wood are still

Table 2. Summary of Nigeria's Export Trade in Logs and Lumber for the Period 1962 to 1972.

YEAR	LOGS MILLION QUANTITY CUBIC FT.	LUMBER MILLION CUBIC FT.	TOTAL MILLION $.
1962	16.2	2.3	26
1963	18.5	2.7	20.3
1964	21.4	3.1	23.7
1965	16.3	2.9	19.4
1966	15.5	2.6	17.4
1967	9.2	1.9	10.7
1968	8.7	2.1	10.7
1969	9.1	2.4	12.6
1970	6.9	1.7	9.3
1971	5.8	1.4	8.0
1972	5.9	1.9	9.5

(Source: Forestry Department of Nigeria Progress Report 1966-1972.)

in sound condition. Though these were in places inaccessible to the common man then. One of the oldest plywood and lumber mill ventured into wooden buildings using concrete slabs as floors. They used a pre-fabrication technique for walls, roof trusses, batten doors and other building components. There were virtually no cost differences between the cement and the wooden houses of the same size. This might be attributed to the low labor cost at the time. This attempt did not meet with much success. Among other things the lack of success was also due to the total importation of foreign designs that did not take into consideration the differences in the climate and social lives of the people. There was poor marketing techniques. The Government was sympathetic with the new idea and was the only major customer.

Housing Needs

Shelter is one of the absolute essentials for the physical survival of man. Housing deficiency in both quantitative and qualitative terms is a generally serious problem in Nigeria. Given the urban character of industrial activities and the substandard condition of most urban dwellings, accelerated urbanization poses very serious problems for the country. Nigeria is a nation about to launch into an era of rapid economic and social transformations.

In addition, there is the need to replace damaged, outmoded and unhealthy dwellings. Also there is urgent need to make adequate housing provisions for the geometric growth in population.

Housing Practices

The present methods of rural and urban dwelling construction buildings have evolved over thousands of years of tradition as well as trial and error. The earthen wall in most urban and rural houses, come in many varieties. They are relatively cool. The thatched roof constitute in effect a porous awning which cuts off the sun and rain but permits the air to move through. This construction makes the best use of local material considering existing technical know-how and capabilities.

Housing developments in Nigeria can be classified broadly into modern urban and rural types.

The modern urban houses are concrete sand stone and cement structures. These are the exclusives of the rich and are very durable, "fort-like" and comfortable. Less than 5% of the houses in the country are of this type.

The term rural type of house is used here to describe houses with earthen wall irrespective of location. Although there are local differences in the construction of these rural houses. For the purpose of this study the rural house will be considered as one single category. Local differences are based on amount of mud used. This varies with the soil characteristics of the location of the house. In latteritic, loamy-clay soil regions, the wall consists of 100% mud. This material can be moulded and when dried retains its shape and increases its hardness, but in clayey sand areas the wet mud is applied to a frame of untreated sapling poles. This frame serves as the structural skeleton or the weight bearing element while the mud serves as a filler and bulking agent, cutting off outside noise and heat.

The stakes or frames have a high percentage of sapwood. Small posts serve also as doors and window frames.

The flooring of the house is most unsanitary. It consists of mud, stabilized by repeated coatings of clayey red or loamy soil, formed into a slug, in some areas, or of cow dung in certain other areas.

Due to the climate the ground is heavily infested with termites. The wooden parts of the house present a good thriving food source for decay fungi and termites. These are very common. And in a very short time the wooden frame is completely destroyed.

The roof trusses are of young stems or untreated lumber. The sheathing material usually is palm leaves for the lowest class of houses or corrugated iron sheets for the not so poor. In some urban areas corrugated iron sheets also serve as wall materials.

Due to the hot weather of the dry season, the palm leaves dry up. They become highly flammable before the onset of the heavy soggy rainy season. They are gradually destroyed by termites and rot fungi and can easily collapse, thus requiring constant checking and replacement.

These houses only provide the most elementary protection against sun and rain. They can be uncomfortable as well as unhygenic. The corrugated iron sheets rust easily in the hot humid weather.

Shortcomings

The present trend in Nigerian modern urban housing design favors durable dwelling construction, usually of steel, sand and cement. This emphasis has made new housing attainable only by the above average Nigerian.

The low per capita income which characterizes the country's relative underdevelopment further excludes and masses from this essential need.

The high cost of this type of construction is due to heavy reliance on foreign and non-indigenous building materials such as cement and steel when substitutes such as wood that would serve the purpose better are allowed to go to waste.

The housing authorities further advance this trend by their foundationless reliance on sand and cement in their building specifications. The Governments are not in a position to provide adequate housing for the masses based on the present system of "modern" building, as experiences with various pilot housing projects indicate.

The financial institutions are too underdeveloped to help out in this situation. The rampant shortages of building materials particularly cement and steel further aggravates the situation.

The isolated attempts made at using wood as a building material failed to take sociological, economic, traditional and climatic factors into consideration in their designs of the houses.

The Government on its own has spent relatively huge sums of money in either starting new cement factories or restoring the older ones that are incapable of profitable operation. Despite this the country still imports more than 50% of its cement at exhorbitant costs to the taxpayers; while at the same time disregarding the natural choice of building material, wood, that the country is so richly endowed with.

The adversaries of wooden building for Nigeria claim that Nigerians are not used to wood buildings, having immigrated from the desert. Also they view the cooking habits as going to cause some potential problems in wooden houses.

This may be countered by saying that the building stage in Nigeria today has been arrived at by trial and error. The idea of building with wood is not strange or new to Nigeria. The state of building as it is today is an adaptation to the environment, forced by climatic and biotic factors negating the construction of total wooden buildings. At this stage of affairs, the wooden elements have been reduced but not completely eliminated; as would have been expected in desert building with their characteristic mud roofs.

Moreover, the coastal dwellers build their houses of wood, which are usually elevated on stilts. Also, among the farming communities of the hinterland, temporary farm buildings are constructed of wood.

Avenues For Improvement

Sociological, economic, climatic and traditional factors as well as structural requirements should be taken into consideration in the design of houses and the choice of building materials.

Housing designs in Nigeria should follow a pattern: the whole house should be built of light materials - wood, with some light plaster stuck on.

The houses should be durable to last 25 to 30 years, but light and elastic. They should be constructed of building elements whose sizes and position can be easily and inexpensively changed. There should be flexibility incorporated into the design and the construction, so that the houses can be extensible or reducible as the size and income of the household dictate. The cost should be as low as possible to be within the means of the masses and the Government can help in this by subsidy plans. When the above requirements are considered against the properties of known and available building materials today, wood is the proper material to build with in Nigeria.

The pattern in Nigerian housing design should be modified by standardization. There should also be pre-fabrication of doors and window frames and shutters; there should be built-in-furniture in the houses. The housing components should be designed on a modular basis.

A really effective acceleration of production in housing, can only be expected from mass production. The building parts should be machine made in the factories. Only the assembly would be carried out at the actual building site.

It has been recognized that tropical timber being mainly hardwoods might not be the best sheathing material, Mielder (35) and Vital et al (12) have found that tropical species make very good particleboards. However, the above workers had their experiences with Burmese and South American wood respectively.

This type of mass production favors the use of materials such as particleboard which could be available in a wide range of board sizes and thicknesses.

Nigeria being a wood exporting country should take advantage of the raw material, wood, it has an abundance as a building material. In doing this she should import the technical know-how for the better utilization of this wood as a source of building material instead.

PREVIOUS WORK

There is more information available on solid wood preservative treatment than on particleboard treatment. It should be noted that, while some of this information gained with solid wood can be readily transferred to particleboard; other available information cannot be so clearly transferred. This is because one is not dealing with only the natural resistance of the species but also with the state of divisions of the particles or exposed areas and such secondary factors as board density which are independent of the specific gravity of the species used.

Board density may increase decay resistance for two reasons: 1) Same reason as found in solid wood. This is discussed later on in this chapter; and 2) Board density increases the amount of preservative per cubic foot of board, if dosage is based on percent by weight rather than volume.

This brings to mind the problem of preservative specification. Belford and Firth (11) concluded that the present volume specification for preservatives i.e. lbs/cubic foot for solid wood should be upheld.

Since the decay resistance of particleboard is determined by measuring weight loss during exposure to the fungus, any other factor causing weight loss would have to be considered a source of error. The exposure of test specimen to fungus attack involves an increase in moisture content requiring reconditioning after exposure for determination of the true weight loss. This moisture cycling produces a considerable hystersis effect in particleboard (ASTM 2017-63) which would affect weight loss determination. No literature reference could be found on this subject.

The usual standard laboratory decay tests for solid wood have been used in evaluating preservatives applied to particleboard in the United States and Europe. For the United States this is basically the soil-block method. The soil-block method has been and is being used by various prominent workers. Among these are Behr (9), ASTM (1), AWPA (2), Clark (17), Huber (27). Merrill and French (31) compared the soil-block technique to other methods such as the soil burial test, block to block and no substrate methods. They concluded that the soil-block method was the best.

Other methods have been tried. Behr (8) in a field test tied 3 pieces of insulation board together. He then set these pieces directly on the soil. The pieces were separated with 1/4 inch pine sapwood slats.

He then placed them in a wooden box with a lattice and partially covered the box to allow slight wetting by rain, he found that the results he obtained were difficult to analyse.

Jackson and Savory (28) working on soft rots, used the agar block method which is prevalent in Europe. Willeitner (51), among others, found that this method gives misleading results. He then suggested using fungus cellar for test purposes. An important agent in a decay test is the fungus. Each fungus exhibits its own characteristics, which differ from those of others. This differential action has been investigated by Merrill et al (34) and Willeitner (51) separately. They concluded that the amount of deterioration varies with and is affected by the species of fungus employed. This is the reason for the choice of two fungi species in this experiment. The choice was Polyporus versicolor and Lenzites trabea. These are also known to decay hardwoods and furthermore, the former is a white rot and the latter a brown rot.

Another factor affecting the deterioration of particleboard, though to a lesser degree than in solid wood, is the natural resistance of the species of wood used. The more resistant the wood, the higher the resistance of the board produced from such species. This trend has been borne out by various workers, Behr (9), Clark (17) and Willeitner (50).

There is not much agreement among the various workers on the exact role of the resin used as binder, as it affects the resistance to decay of particleboard. Stolley (43) found that such effects depend on the fungal species and the type of binder. He found that Coniophora crerbella caused twice as much weight loss for a urea formaldehyde resin board than for a phenol formaldehyde bonded board. But Poria varporaria showed little or no preference for either type of binder.

Clark (17) found that the decay resistance could be increased, by increasing the amount of urea formaldehyde resin from 4% to 8%. But increasing the amount of phenol formaldehyde resin from 3% to 6%, had no effect on decay resistance. He then concluded that the amount of resistance to decay offered by increasing the amount of resin used depends on the type of resin involved.

Willeitner (50) on the contrary, concluded from his work that while urea formaldehyde resin promoted fungal growth; phenol formaldehyde resin actually had an impeding effect on the fungal growth.

Walters and Chow (49) working with urea formaldehyde, pentachlorophenol and Lenzites trabea; found that the amount of adhesive had little or no effect on either solution absorption or weight loss.

Hann, Black and Blomquist (26) found that boards with phenol resin binders appeared generally more durable than boards with urea resin binders. They also found that the addition of 1% wax improved durability. Furthermore, increase in board density improved both original strength properties and durability. They concluded that binder variables, have a major influence on exterior durability of unprotected particleboard, using strength as an indicator. There might be more to this than decay, like the effect of weathering.

Factors like particle size, shape and distribution have been investigated more with regard to strength properties rather than with their effect on resistance to decay. Notable among these investigators is Turner (47) who found that with optimal particle shape particleboard can develop strength and dimensional stability comparable to plywood. He used long flat flakes in the fabrication of the experimental boards.

The effect of particle size on decay resistance has been investigated by Willeitner (50). He concluded that size and distribution of the particles affect fungal growth. He found that small particles in a dense board impeded fungal growth, but particle shape had little effect on decay resistance.

The influence of physical properties, particularly specific gravity, on decay resistance in particleboard has been examined in great detail by few workers.

Hann et al (26) concluded in passing, that density affects durability. Durability means more than decay resistance.

Other workers are: Clark (17) who in the discussion of his results said among other things; "--- increasing the board density from a specific gravity of 0.53 to 0.66 appeared to have no effect on decay resistance ---". In the above the author was referring to phenol resin bonded particleboard. He went further, saying "--- and that the specific gravity --- which reflects primarily differences in degrees of compression appeared to influence moderately the decay resistance of urea formaldehyde bonded panels ---".

Behr and Wittrup (10) worked on decay and termite resistance of two species particleboards. They concluded that among other things that Redwood-jack pine particleboards of specific gravity .60 or higher were more resistant to *Lenzites trabea* in soil block tests than could be accounted for on the basis of redwood and susceptibility alone.

Willeitner (50) also concluded that increasing the density of medium density boards had no effect on resistance to decay. There is no agreement on the effect of density on decay resistance.

Since the necessity for preservative application due to greater use of particleboard in places of more severe exposure to moist situations is generally accepted; it might be worthwhile to investigate further the influence of density on preservative efficiency. Also since no systematic studies appear to have been reported with regards to the influence of particleboard density on preservative threshold values, it might serve some good looking at what has been done for solid wood.

By far a greater amount of investigation has been carried out in relationship of density to decay resistance in solid wood. Despite this enormous amount of work there was much confusion for a long time.

One of the earliest workers was Zeller (52). He concluded that in heartwood of certain species, the decay resistance was inversely related to density. But for the sapwood of these same species, there was no dependence of resistance to decay on density. This finding was disputed by Buckman (15), who found no such relationship.

Many workers have made passing reference to possible effect of density on the rate of decay. Among these were, Cartwright and Findlay (16), working with different species, they concluded that in general, dense timber tend to be more durable than less dense timber. These observed differences in rate might be due to gaseous diffusion, which is slower in more dense woods. The retardation of the hyphal growth due to diminished oxygen supply and accumulation of carbon dioxide around them were other reasons given for this difference in decay rate.

In a comprehensive study, Southam and Erlich (41) concluded that for a single species of wood, there is a tendency towards a greater initial decay resistance in wood of higher specific gravity. This is nullified or even reversed with time as the decay progresses.

Other workers at different times and on different species found no established relationship between density and natural durability. Among these were, Rennerfelt (39) on scots pine, Suolahti (45) and Gaumann (24) on European larch, and Jorgensen (29) working on hardwoods. Englerth and Scheffer (22) suggested that density may not be itself a determinant factor in resistance to decay; it has an indirect influence, by its relationship to other factors that influence resistance to decay, such as presence or absence of wood extractives. Working with scots pine, Miller and Meyer (36) found that wood density had no significant effect on the rate of decay. Arzumanyan (6) artificially increased the density of pine blocks by radial compression. He found that the samples of increased density showed increased resistance to decay by Coniophora cerrebella. A similar situation might exist with particleboard. Resistance in the case of particleboard will be further enhanced by the resins and waxes as regards influence of density on threshold values for preservatives.

Belford and Firth (11) found that density alone did not significantly influence the performance of a preservative against wood destroying fungi as measured by threshold values.

Toole and Barnes (46) found that the resistance of particleboard to fungal attack is superior to that of solid wood. But this greater resistance does not make particleboard "fungi proof". Chemical protection is necessary when the board is to be used under humid condition.

That it is possible to incorporate chemical preservatives in particleboard has been proven beyond doubt by the works of Huber (27), Narayanamurti et al (37), Walters and Poo Chow (49), Gersonde and Deppe (25), Deppe (18), and Deppe and Petrowitz (19), who used either pentachlorophenol or its sodium salt.

Stolley (43) considered 1% to 2% of pentachlorophenol, on the basis of the weight of solid wood substance, to give satisfactory protection against fungi. Narayanamurti et al (37), reported satisfactory protection with 2% to 5% of pentachlorophenol. Merrill and French (31) obtained threshold values of 0.4% for pentachlorophenol while the corresponding values obtained by Huber (27) using sodium pentachlorophenate were between 0.30% and 0.65%, on dry wood basis. Deppe and Petrowitz (19) reported that 2.5% pentachlorophenol was not certain to give protection against wood destroying fungi. This is because only about 1.8% is left in the board after pressing, as the chemical, PCP is very volatile.

Countless wood preservatives have been investigated for their suitability as protective treatment for particleboards. Many of these have proved to be unsatisfactory, either by reason of their incompatibility with the binder, or their toxicity to man and animal, or due to their low solubility. The utilization of pentachlorophenol has been investigated by many workers. Deppe and Petrowitz (19) noted that while pentachlorophenol has proved to be very good in practice, it has some problems. One such problem is, when the chemical is used as a basic salt or in an organic solvent, it might precipitate out in solution. Also an increase in the amount of PCP has been known to reduce the tensile strength perpendicular to the surface of the board substantially, (Deppe and Petrowitz. 1969).

Huber (27) in his appraisal of the preservative effectiveness used the laboratory soil-block method. He found that the most satisfactory method of adding preservative to particleboard, bonded with urea formaldehyde or phenol formaldehyde resins, is by addition of the chemical to the resins before spraying the furnish. He noted that this method produced boards that looked good for commercial use. This method had no adverse effects on the strength properties of the boards.

Similar work was carried out by Narayanamurti et al (37). They mixed sodium pentachlorophenate with the glue, and blended this into the chips or furnish using a blender. They produced experimental boards which they subjected to decay tests. They concluded that about 5% to 2%, (based on dry wood weight), of NaOPCP is needed to give satisfactory protection. This figure is much higher than the 0.30% to 0.65% obtained by Huber (27).

Some objections to treating the flakes rather than the boards, are on the ground that PCP is very volatile and thus a substantial amount can be lost in the hot press. Becker (7) expressed this view, pointing out that the premanence of pentachlorophenol is limited. This view was also expressed by Deppe and Petrowitz (19).

But using the above method, Walter and Chow (49) obtained significant differences in the average weight loss of test specimens; 0.25% for treated specimens and 19.58% for untreated specimens.

If the loss of preservative during the pressing cycle is taken into account, the threshold value obtained by Merrill and French (31) for pentachlorophenol might be on the low side.

Most of the available literature on treatment of particleboard deal with research work, and very little work can be found on industrial treatment process. The exception to this might be Europe, particularly in Germany, where much particleboards are employed in places of high risk of attack by decay fungi, in buildings. In fact, the German government stipulates mandatory treatment of particleboards to be employed in such places.

Many workers agree that physical properties affect the durability of particleboards; but there is general disagreement on the extent and direction of such effects. This might be due to the non-standarization at present of test methods for particleboards, as separate from the standards for solid wood test methods.

PROCEDURE

General

The experiment was designed so that the same level of preservative treatments is applied to two different sets of boards that differ in nominal density. The furnish material for the boards was to be a tropical timber species.

The boards were made in the laboratory under close control of the board composition and process variables. This helped to eliminate variations among the boards due to such variables. The boards were tested for strength properties as well as decay resistance after pentachlorophenol had been incorporated in the boards.

Manufacture of Boards

Raw Materials

The flake was made from Triplochiton scleroxylon, K. Schum "Obeche", a tropical hardwood species with a density of 24 lbs. per cubic foot. Obeche grows up to 150 feet tall and greater than 6 feet in diameter. It is a native of the central part of West Africa; a fast growing species with whitish wood, that works and glues well but has little resistance to decay and blue stain fungi.

The wax used was Paracol 404N.

The preservative used was sodium salt of pentachlorophenol. Details of the addition are in the next section.

The binder was a phenol formaldehyde resin called Cascophen PB-65. The data sheet is included as Appendix I.

Manufacture of Flakes

The lumber was obtained kiln dried. The problem was to make a suitable furnish of this type of raw material. The furnish was to be as similar as possible to an industrial or commercial furnish. The dried lumber was cut into 3 inch pieces, across the general direction of the grain. This size of 3 inches, was due to the limitations imposed by the laboratory flaking machine. These pieces were subjected to a vacuum of 30 inches of mercury for 30 minutes while submerged in water. A pressure of up to 150 psi was applied for 30 minutes after the release of the vacuum. The pieces were then allowed to soak in water for 24 hours.

The pieces were then flaked in the laboratory flaking machine, shown in Plate 1. The knives were set to produce a flake thickness of 0.014. The resultant flakes were measured and the frequency of the thickness distribution plotted (Figure 1). The average thickness was 0.014 ± .003".

The flakes were then passed through a laboratory hammer mill, with a screen size of 0.375 inches in place. The furnish was first air dried and then dried at elevated temperatures to 4% moisture content.

A screen analysis of the dried furnish was made, using different screen sizes and a Cenco-Meinzer sieve shaker. The relative frequency of the different size fractions was plotted on histogram at Figure 2 and tabulated in Table 3. The actual size fractions of such furnish are shown in Plate 2.

Particles passing through screen size No. 5 (0.0117 inch mesh) were screened out as dust. Such fine material does not contribute to the strength properties of the board. This fraction of fines was about 18.5% of the total furnish.

Addition of Resin, Wax, and Preservative

Apparatus - The set up for the addition of resin, wax and preservative is shown in Plate 3. It consists of a modified one liter (1,000 cc's) measuring cylinder, drawn out at the base. A 10 mm stopcork was then attached to the base. This was the receptacle for the fluids to be sprayed.

A rubber tubing connected the stopcork at the base of the cylinder to a spray gun. The nozzle of the spray gun was directed at the mouth of a cement mixer covered with fine wire mesh to allow the air to escape from the mixer.

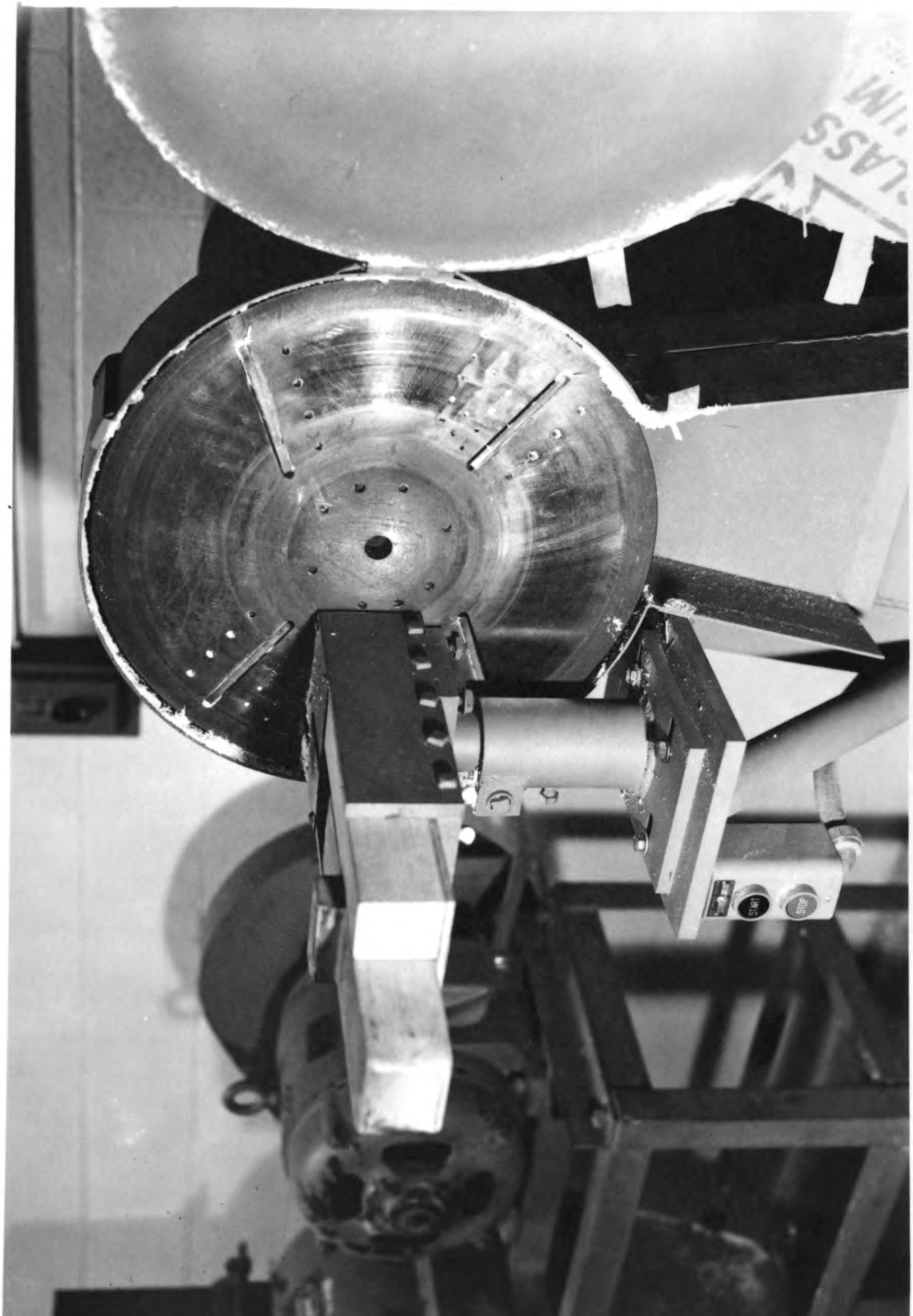

PLATE 1. Laboratory Flaking Machine.

FIGURE 1. Shows the thickness distribution of the flake materials. The mean thickness was 0.0141 ± .0031 at a moisture content of 8.75%.

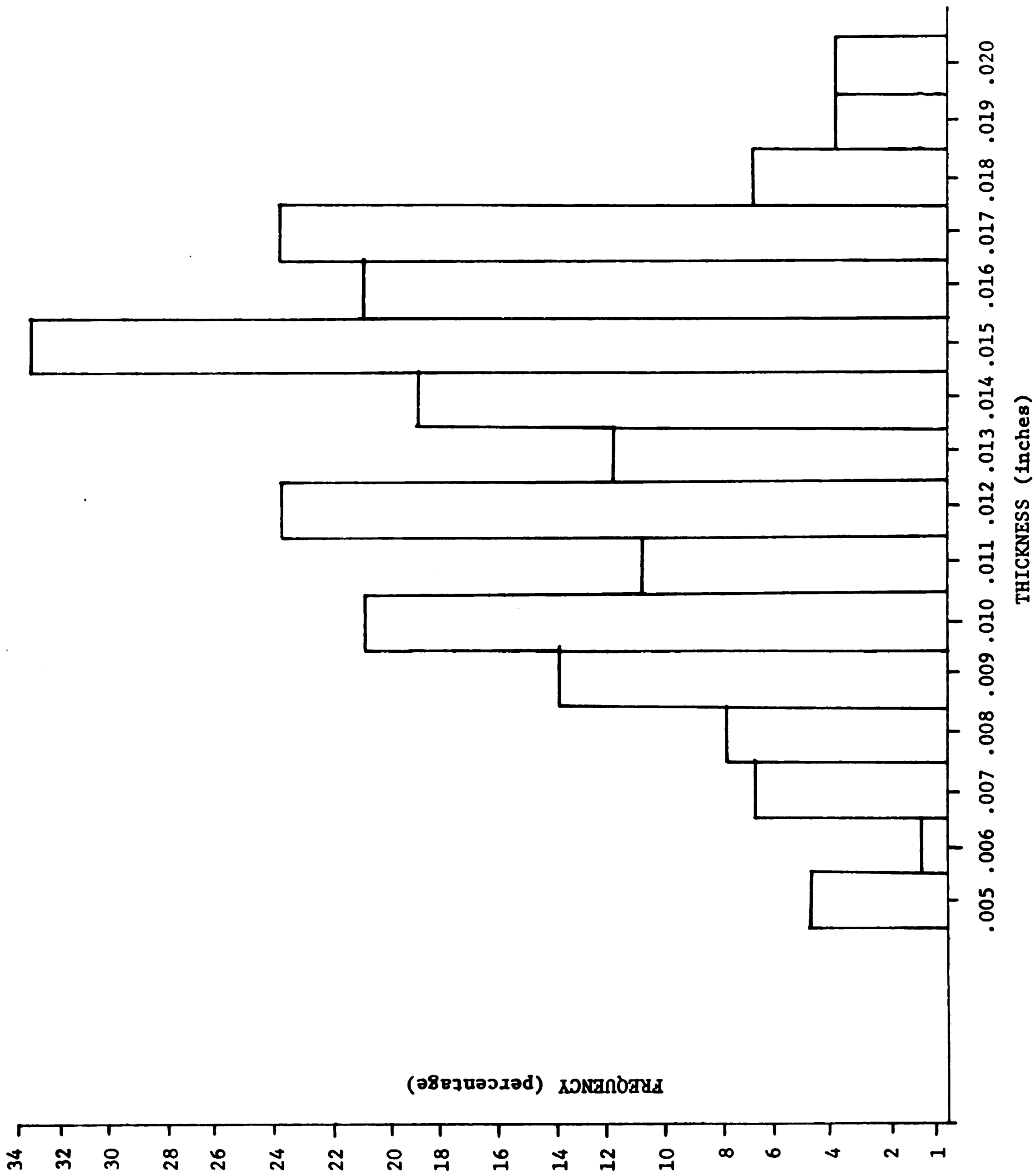
FREQUENCY (percentage)
34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 1
THICKNESS (inches)
.005 .006 .007 .008 .009 .010 .011 .012 .013 .014 .015 .016 .017 .018 .019 .020

FIGURE 1.

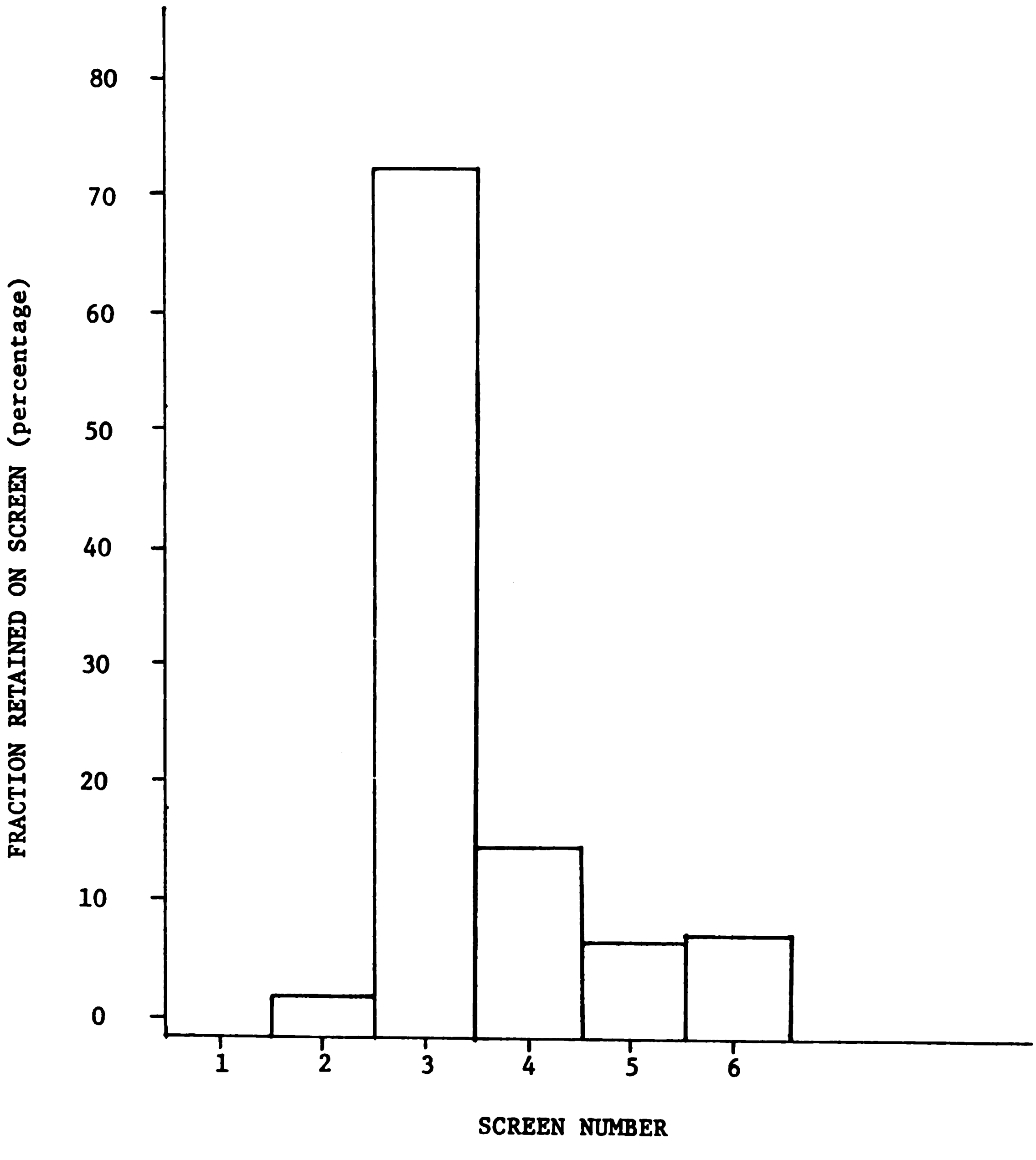

FIGURE 2. Histogram of Furnish Screen Analysis.

Table 3. Screen Analysis of the Furnish Material for the Boards.

SCREEN NO.	MESH (inches)	FRACTION OF FURNISH RETAINED (%)
1	0.187	0.02
2	0.0937	2.8
3	0.0469	62.8
4	0.0232	15.8
5	0.0117	8.1
6	less than 0.0117	10.4

The spray gun was adjusted to wide angle spraying. The flow was adjusted to about 78 mls. per minute. Eight percent phenol resin and 1% paracol wax were used, based on the dry wood weight.

The preservative was mixed with the adhesive. The sodium pentachlorophenate was in pellet form. Water, alcohol, and acetone were tried as possible solvents as well as direct dissolution in the phenol adhesive, but these methods were unsatisfactory due to insufficient amount of the preservative dissolving in the above solvents. The preservative was found to be 30% soluble in Methyl Ethyl Ketone. This solvent was then used for the preparation of a 30% stock solution of the preservative. While this solution was found to be compatible with the adhesive, it precipitated the wax in a mixture.

Process

A master table for the required amount of furnish, preservative, wax and resin was drawn up for each board.

The required amount of furnish was weighed and put in the mixer and tumbled. The measured amount of the preservative and the phenol

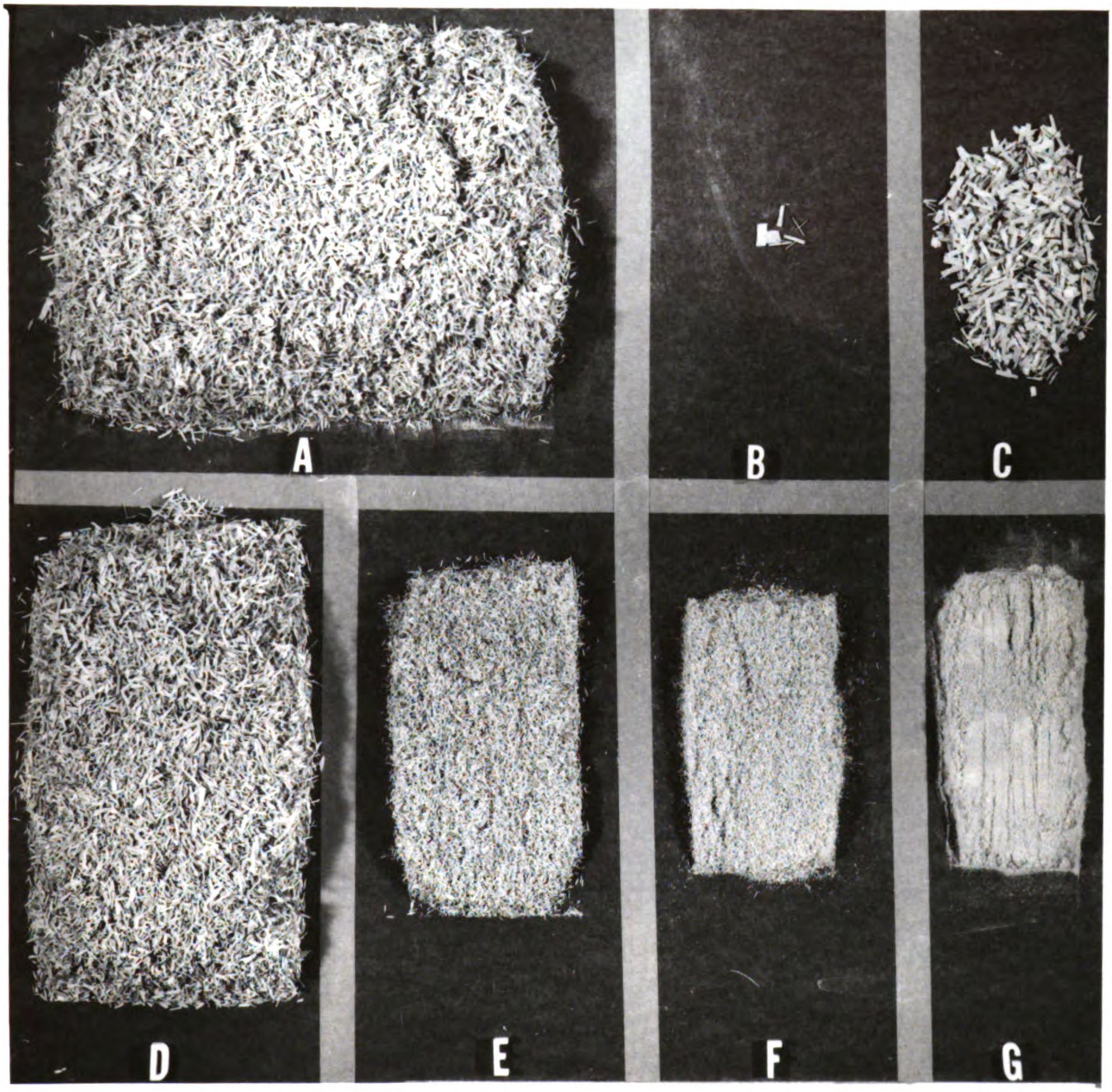

PLATE 2. Screen Analysis of the Furnish.

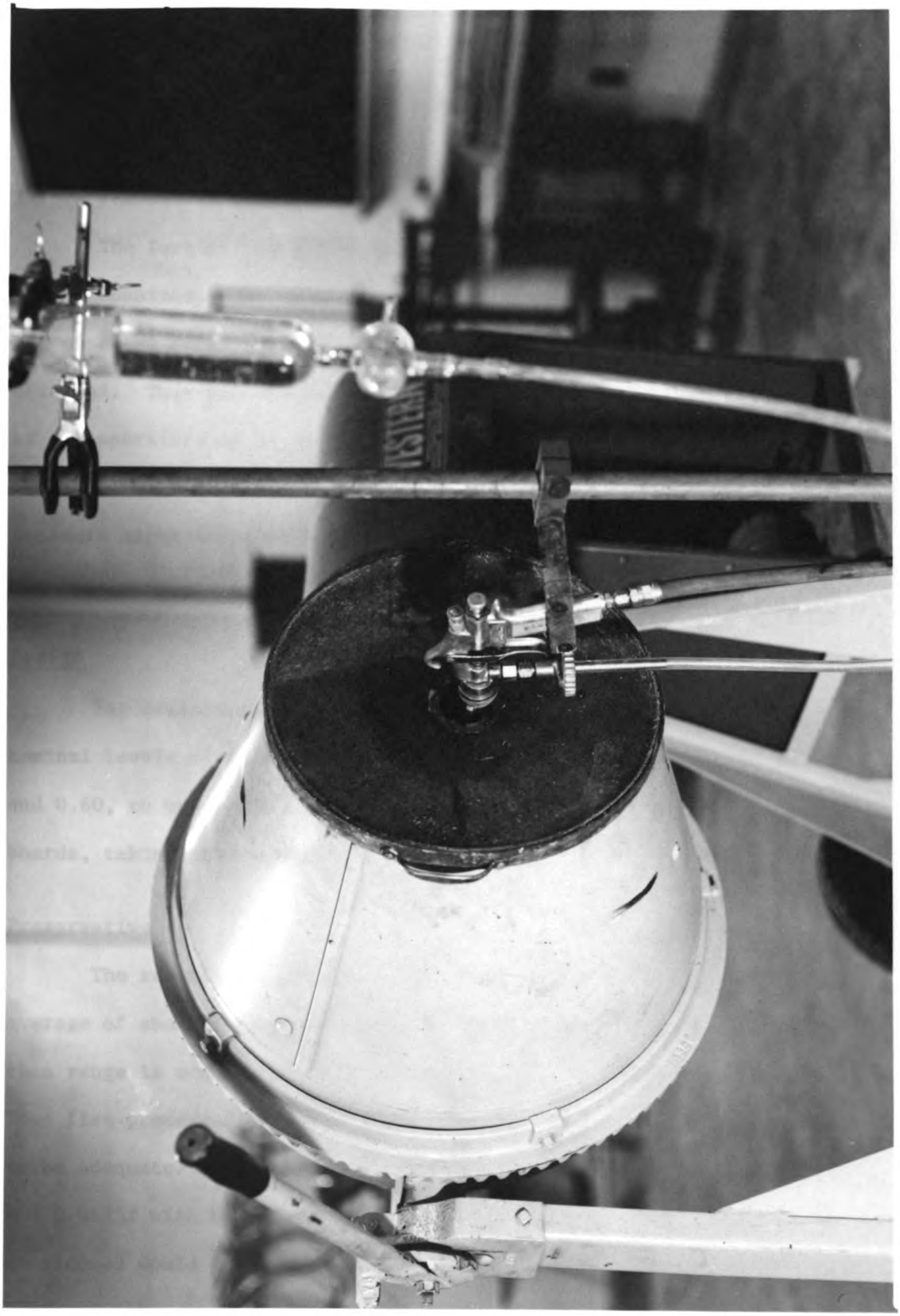

PLATE 3. Apparatus Set Up for Furnish Preparation.

resin were mixed thoroughly, and sprayed from the measuring cylinder onto the furnish being tumbled. Then the correct amount of wax was sprayed on. The furnish was tumbled and mixed for about 5 minutes before removal to a container.

The furnish was hand-formed into a mat in a mould of 16" x 16" x 5" dimensions. The formation was by random distribution and leveling out of every added quantity of furnish until an even surface was obtained. This mat was pre-pressed manually. The boards were pressed at a temperature of 380 degrees fahrenheit, in a Berthelsen, single opening, oil heated press. The pressure used was 600 psi. This pressure might be considered high, but it was used to develop high physical strength properties values.

Design

The details of the design of the experiment are in Table 4. Two nominal levels of specific gravity were decided upon. These were 0.45 and 0.60, to cover the practical range of densities for medium density boards, taking into account process variables.

Preservative

The results of previous work would suggest a threshold value average of about 1.5% with a range of 0.3% to 5%. The upper limits of this range is considered high for the purposes of this investigation. Thus five preservative levels with a maximum level of 1% were considered to be adequate. The preservative levels were 1%, 0.5%, 0.25%, 0.125%, and 0.0625% with 0% preservative level as control. This range, it is considered would include and exceed the threshold value for this

Table 4. Design of the Experiment and Summary of Mechanical Test Results.

The values for the moduli of elasticity and rupture are the averages to two test results. The internal bond values are averages of three test results.

Table 4. Design of Experiment and Summary of the Mechanical Test Results.

SPECIES	"OBECHE" *Triplochiton scleroxylon*											
Nominal Specific Gravity	0.45						0.60					
Preservative Treatment Level %	1.00	0.50	0.25	0.125	0.0625	0	1.00	0.50	0.25	0.125	0.0625	0
Replication	1	1	1	1	1	1	1	1	1	1	1	1
Decay Test Specimens	20	20	20	20	20	20	20	20	20	20	20	20
Modulus of Elasticity psi	508900	409900	382900	348300	379200	333500	576300	589300	579000	463100	453600	548300
Modulus of Rupture psi	3040	3090	3070	2640	2920	2450	4950	5180	5000	5020	4010	4470
Internal Bond	41	68	66	75	56	50	103	106	90	115	111	91
Specific Gravity	.57	.57	.56	.53	.54	.51	.66	.68	.70	.70	.68	.68

investigation. There was a second control using solid wood with 0% preservative level. All levels were based on dry wood weight.

Tests

Physical Tests

Twelve boards were made. They were trimmed and then allowed to equilibrate with room condition. The boards were then cut according to the design shown in Figure 3. From each board two 3" strips, for the strength test were cut from the inner 8" of the board. The specimens used for the internal bond tests, were cut out of the middle 2" of this 8" wide piece.

The test for modulus of elasticity was done using a non-destructive method of natural resonance. The test arrangement is shown in Plate 4. The modulus of rupture and internal bond tests were carried out according to ASTM 1037-64 specifications.

The results of the physical properties test are in the lower part of Table 4.

Decay Tests

The decay test specimens were cut out from the strips tested for the physical strength properties. Each piece was measured and weighed. The nominal sizes for the test specimen were 1" x 1" x 5". The 0.5" was the nominal thickness of the boards. The general direction of the orientation of the wood chips in the boards were in planes parallel to the surfaces of the board.

FIGURE 3. Shows the Design Followed in Preparation of the Experimental Test Pieces from the Manufactured Boards.

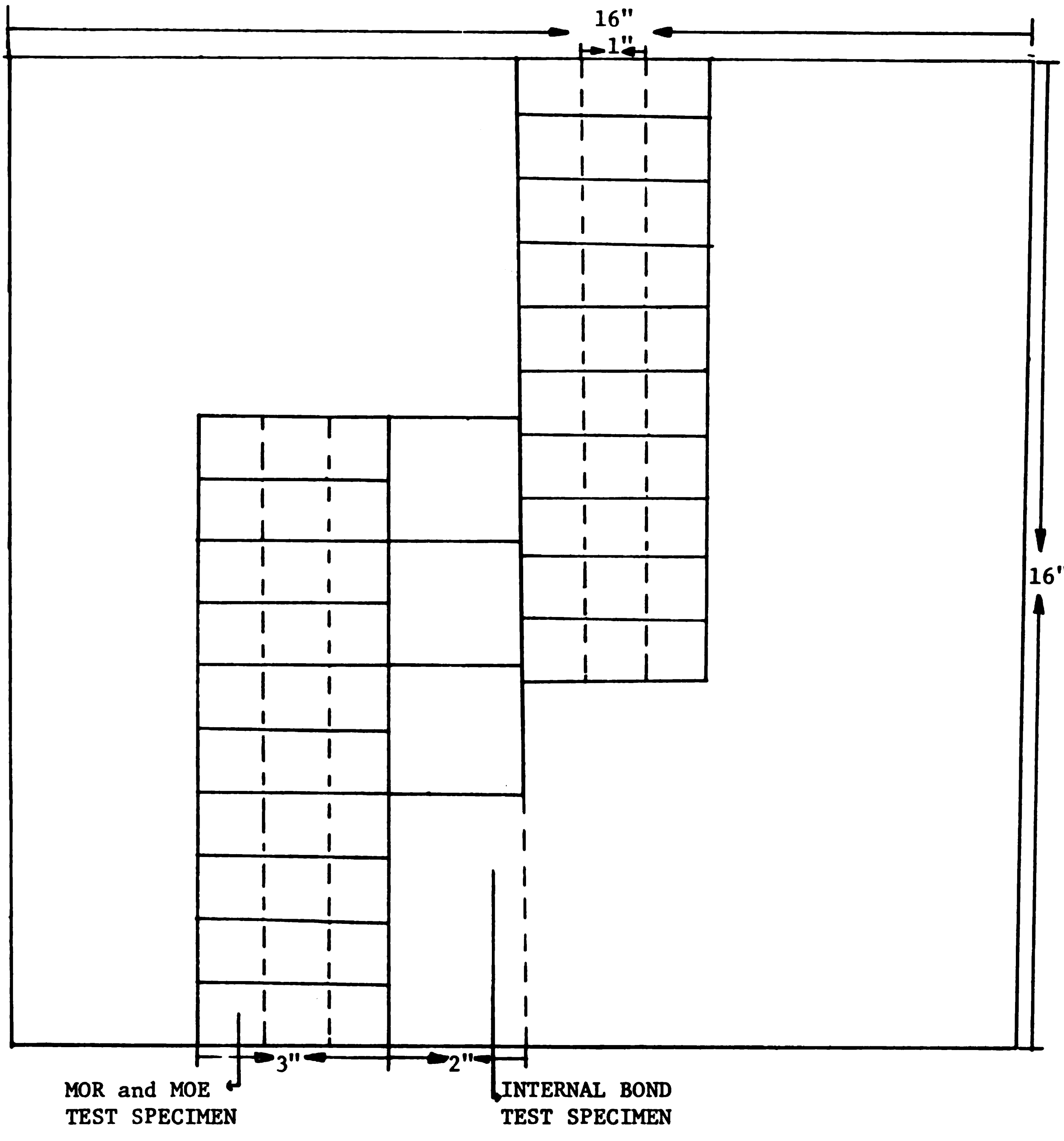

FIGURE 3. Design for Specimen Cutting.

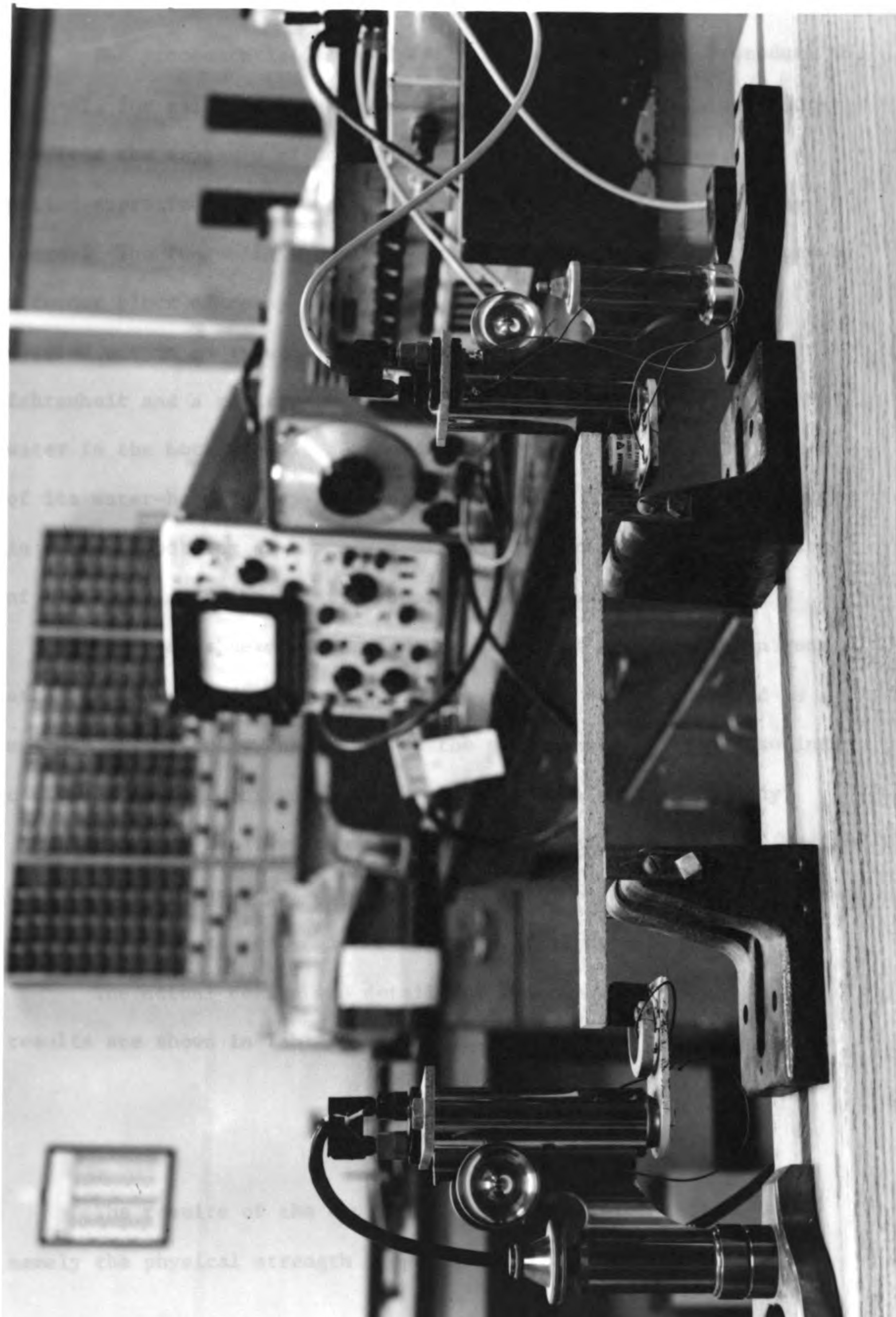

PLATE 4. Equipment for Dynamic Test.

The procedure laid down in AWPA and ASTM Standard Procedure No. 1413-61, for soil-block test was followed (1), (2). This procedure involved the exposure of conditioned and weighed specimens, for a period approximately 12 weeks to a pure culture of selected decay fungus. The fungus is grown in bottles on a substrate soil topped by a feeder block of decay susceptible wood. The conditioning was carried out in an incubation room at a temperature of 80 degrees fahrenheit and a relative humidity of 70 percent. The percentage of water in the bottled soil during culture preparation was 130 percent of its water-holding capacity. This ensures a high relative humidity in the test bottles at the start of the exposure. During the course of the experiment the relative humidity might come down.

The test specimens were reconditioned in the incubation room after exposure, and then weighed. The loss in weight was used as a measure of the decay resistance of the specimens. This is also indicative of the effectiveness of the preservative applied, if any.

Two test fungi were used, Lenzites trabea Pers. ex Fr. (Madison 617) and Polyporus versicolor L. ex Fr. (Madison 697). The specimens were exposed to these fungi for a period of 14 weeks.

The actual design and details of the experiment with some results are shown in Table 5A and 5B.

RESULTS

The results of the experiment are presented in two parts, namely the physical strength properties and the decay resistance.

Table 5A and 5B. The Design and Summary of the Decay Tests for the Two Fungi, *Polyporus versicolor* and *Lenzites trabea*, and the Two Nominal Density Levels, 0.45 and 0.60.

The test method was the soil-block with feeder strips.

The treatment levels were based on the dry wood weight.

Table 5A. Design of Decay Test Experiment and Summary of the Results.

FUNGUS		*Polyporus versicolor*											
NOMINAL SPECIFIC GRAVITY		0.45						0.60					
(Percentage) TREATMENT LEVELS		1.00	.50	.25	.125	.063	0	1.00	.50	.25	.125	.063	0
NUMBER OF SPECIMENS		10	10	10	10	10	10	10	10	10	10	10	10
WEIGHT LOSS %	Average	-2.06	-1.53	-.669	2.023	.392	6.984	-1.40	-1.294	-1.446	-1.605	.913	-1.029
	Standard Deviation	.356	.476	1.734	3.817	2.458	8.839	.524	.437	1.363	.552	3.041	1.329
SPECIFIC GRAVITY	Average	.575	.570	.551	.549	.508	.518	.705	.673	.673	.751	.728	.743
	Standard Deviation	.016	0.18	.0118	.020	.025	0.011	.034	.016	.038	.019	.026	.013

*Negative values indicate weight gain.

Table 5B. Design of Decay Test Experiment and Summary of the Results

FUNGUS		*Lenzites trabea*											
NOMINAL SPECIFIC GRAVITY		0.45						0.60					
(Percentage) TREATMENT LEVELS		1.00	.50	.25	.125	.063	0	1.00	.50	.25	.125	.063	0
NUMBER OF SPECIMENS		10	10	10	10	10	10	10	10	10	10	10	10
WEIGHT LOSS %	Average	-.591	-.253	2.633	6.365	5.259	40.439	-.379	-.037	1.261	1.887	12.226	12.824
	Standard Deviation	.250	.711	1.868	4.292	11.227	10.786	.699	.196	1.38	2.327	6.174	6.407
SPECIFIC GRAVITY	Average	.557	.579	.586	.574	.560	.481	.706	.733	.667	.738	.694	.654
	Standard Deviation	.016	.017	.022	.013	.014	.023	.043	.016	.033	.020	.038	.043

*Negative values indicate weight gain.

Physical Strength Test

The average values for the physical strength tests are included in Table 4, with the experimental design.

For the nominal specific gravity of 0.45, the modulus of elasticity ranged from 333,500 psi to 508,900 psi. The corresponding values for the nominal density 0.60 were 453,600 psi to 589,300 psi.

Values of the modulus of rupture as in Table 4, ranged from 2,450 psi to 3,090 psi for the nominal specific gravity of 0.45. The corresponding values for the nominal specific gravity of 0.60 were 4,470 psi to 5,180 psi. The values shown are averages of two tests.

It will be noted that within these nominal densities, there was a positive correlation between the individual board densities and the modulus of rupture and elasticity for the respective boards.

The values for the internal bond tests were 41 psi to 75 psi for the nominal specific gravity of 0.45. The values obtained for the nominal specific gravity of 0.60, were 90 psi to 115 psi. Each value represents the average of three test pieces.

The values for nominal specific gravity 0.45 were rather low. This may be explained by the effects of the lower density and the shorter closing time (in seconds).

These above values for the strength properties indicate that the minimum strength properties requirements of commercial mat-formed wood particle CS 236-66 could easily be met by this type of board.

Decay Test

Tables 5A and 5B show the results per fungus species and nominal density level. The values as shown are averages from ten such pieces.

The action of the two fungi as indicated by percentage loss in weight of the test pieces were not the same. The differences in 0.45 nominal specific gravity control pieces were of the order of 6.9% weight loss for Polyporus versicolor and 40.4% weight loss for Lenzites trabea. The corresponding values for the particleboards of the 0.60 nominal specific gravity were -1.0% and 12.8% for Polyporus versicolor and Lenzites trabea respectively. The weight loss values obtained for untreated solid wood were 58.1% and 15.6% for Lenzites trabea and Polyporus versicolor respectively, Appendix II. Lenzites trabea obviously thrived better than Polyporus versicolor thus causing more decay or weight loss.

ANALYSIS

Figures 4 to 7 summarizes graphically the average weight loss in percent plotted against the preservative concentration in percent. Each point is the average of ten test specimens values. The graphs showed a curvilinear relationship. Thus, if one straight regression line was put through all the points corresponding to the values for one nominal density per fungus, misleading results would be obtained.

The points were subdivided on the basis of linearity. Regression lines were drawn through groups of points showing linear relationship. Thus one regression line joined the points for values of 1% and 0.5% preservative concentration. The other line was fitted through the points for the values obtained for 0.25%, 0.125% and 0.0625% levels of preservative concentration. The 0% preservative concentration was not included in this analysis.

FIGURE 4. Shows the percentage weight loss plotted against preservative concentration for the nominal specific gravity of 0.45, using *Lenzites trabea* as the test fungus.

The intercept of the regression line on X axis was $26 \times 10^{-2}\%$, i.e. the threshold value.

The equation of the line was Y = 18.258 - 6974.895X.

The equation of the line indicates the slope, a less stable measure compared to the intercept of the lines as a measure of threshold, due to the effect of hystersis.

The slope of the line was Y = 18.258 - 6974.895X.

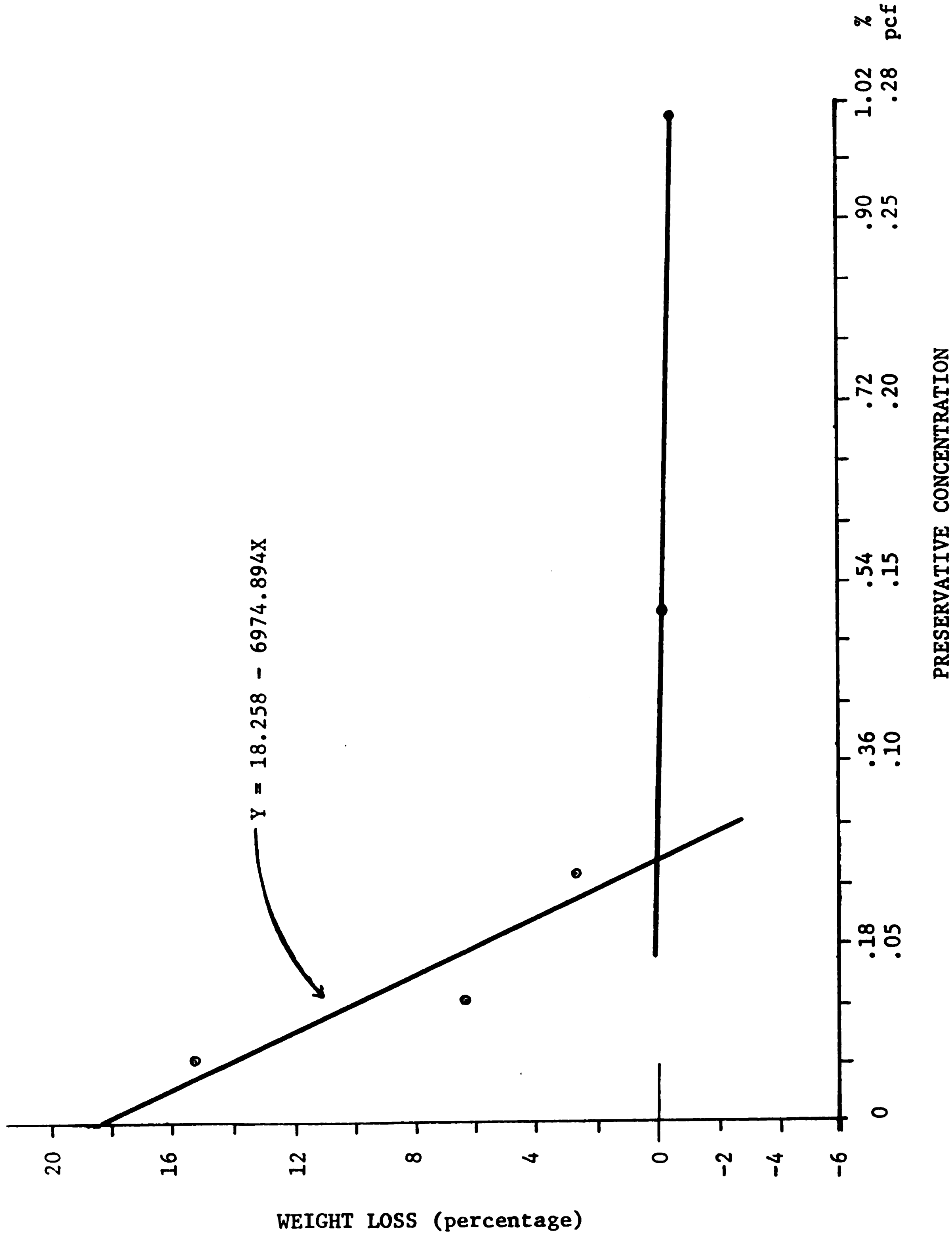
Y = 18.258 - 6974.894X
WEIGHT LOSS (percentage)
20
16
12
8
4
0
-2
-4
-6
PRESERVATIVE CONCENTRATION
0
.18
.05
.36
.10
.54
.15
.72
.20
.90
.25
1.02
.28
%
pcf

FIGURE 4

FIGURE 5. Shows the percentage loss in weight of the test pieces plotted against the preservative concentration percent, for the nominal specific gravity of 0.60, using Lenzites trabea.

The equation of the line and the threshold value are: $Y = 13.467 - 5720.926X$ and $23.5 \times 10^{-2}\%$.

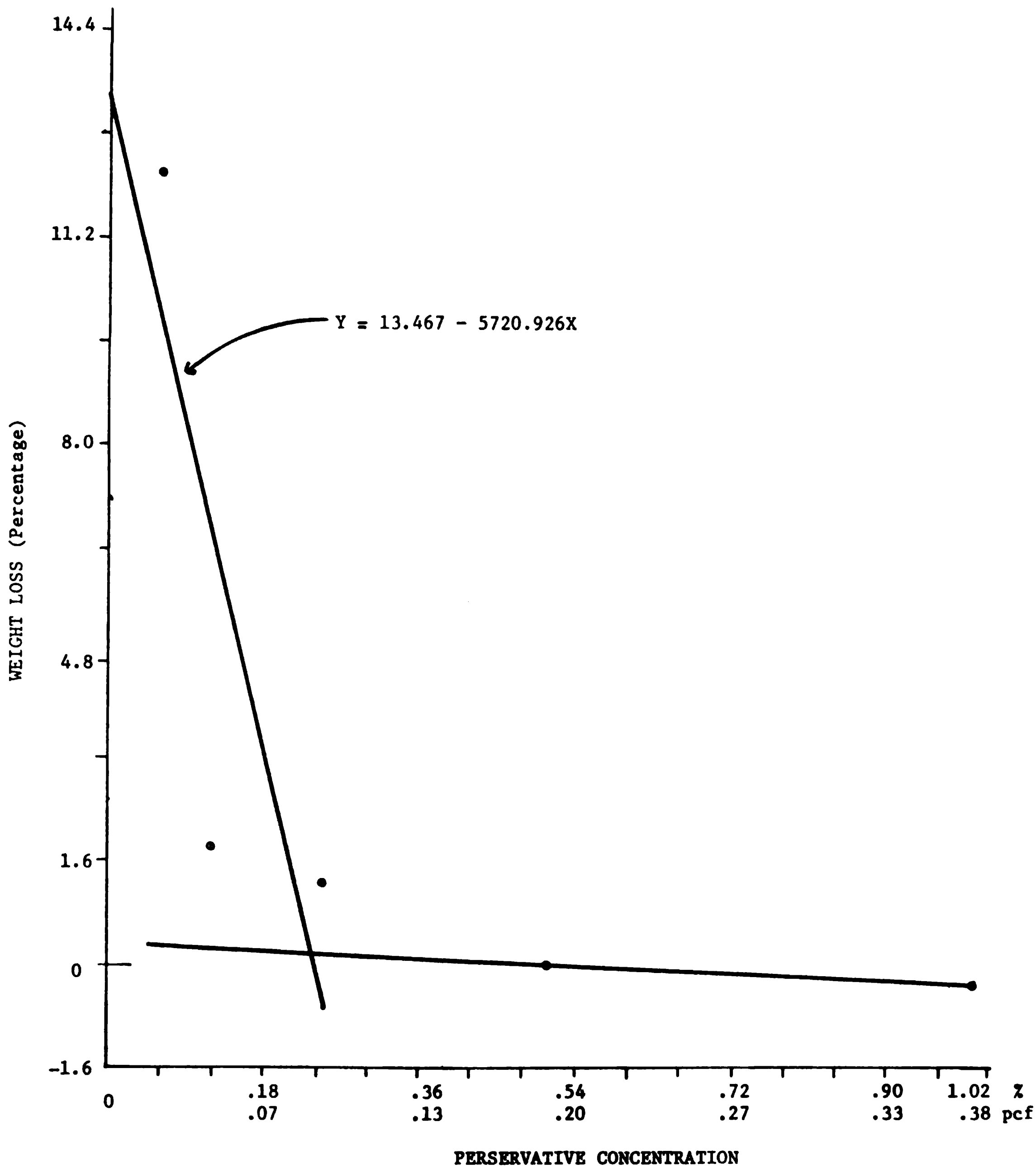
14.4
11.2
8.0
4.8
1.6
0
-1.6
WEIGHT LOSS (Percentage)
Y = 13.467 - 5720.926X
0
.18
.07
.36
.13
.54
.20
.72
.27
.90
.33
1.02 %
.38 pcf
PERSERVATIVE CONCENTRATION

FIGURE 5.

FIGURE 6. Is the percentage loss in weight of the test specimens plotted against preservative concentration for the nominal specific gravity of 0.60, using Polyporus versicolor as the test fungus.

The points were erractic and the regression line was positively sloping. For the purposes of this experiment the results from this test might be disregarded.

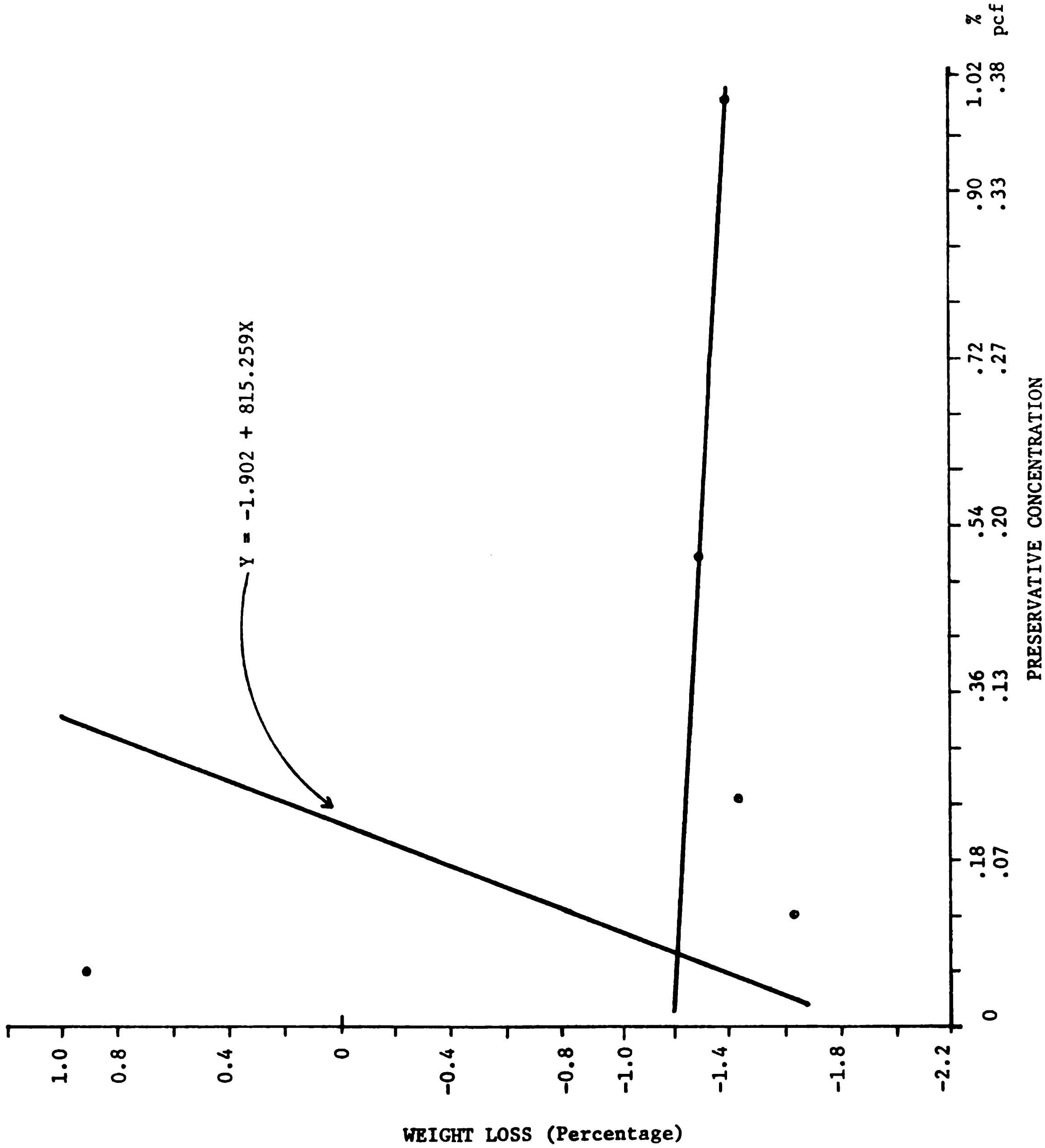
Y = -1.902 + 815.259X
WEIGHT LOSS (Percentage)
1.0
0.8
0.4
0
-0.4
-0.8
-1.0
-1.4
-1.8
-2.2
PRESERVATIVE CONCENTRATION
%
pcf
0
.18
.07
.36
.13
.54
.20
.72
.27
.90
.33
1.02
.38

FIGURE 6.

FIGURE 7. Shows the percentage loss in weight plotted against preservative concentration for the nominal specific gravity of 0.45, using *Polyporus versicolor*.

Replication was 10.

The equation of the line was: $Y = 1.883 - 892.167X$.

The intercept of the line on the X axis was at: $36.8 \times 10^{-2}\%$.

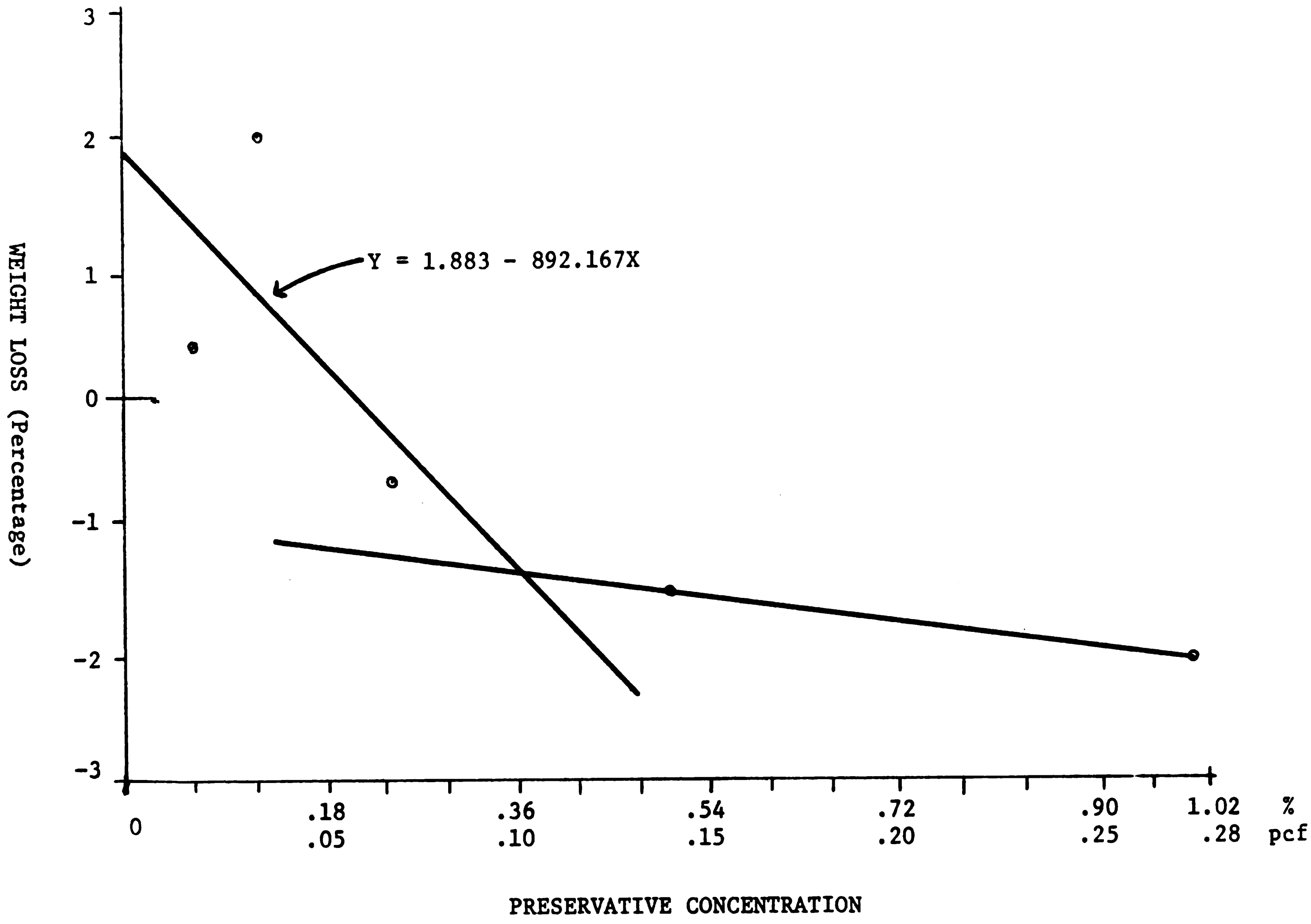
3
2
1
0
-1
-2
-3
WEIGHT LOSS (Percentage)
Y = 1.883 - 892.167X
0
.18
.05
.36
.10
.54
.15
.72
.20
.90
.25
1.02
.28
%
pcf
PRESERVATIVE CONCENTRATION

FIGURE 7.

Threshold values were determined graphically. If treatment levels included or ranged beyond the true threshold values, then a representation of such values would take the form of broken lines. The true threshold value would be where the weight loss leveled off.

Of the four representative graphs only Figure 4 and 5 are good examples of this procedure. These can readily be evaluated. The threshold values are at intercept of the two regression lines on the X axis. These values were $26 \times 10^{-2}\%$ and $23.5 \times 10^{-2}\%$ for nominal specific gravity 0.45 and 0.60 respectively, using Lenzites trabea as fungus.

The other two resultant graphs were erractic. Both showed negative weight loss values up to 1.6%. In Figure 6, analysis was impossible and no meaningful threshold values could be determined. The regression line had a positive slope.

Tables 6A and 6B summarize the results of the analysis.

Table 6A. Summary of Threshold Values by Regression Analysis.

FUNGUS	NOMINAL SPECIFIC GRAVITY LEVELS	INTERCEPTION ON X AXIS (Concentration Percentage)	EQUATION OF LINE
Polyporus versicolor	0.45	36.8×10^{-2}	$Y = 1.883 - 892.167X$
	0.60	8×10^{-2}	$Y = -1.902 + 815.259X$
Lenzites trabea	0.45	26×10^{-2}	$Y = 18.258 - 6974.895X$
	0.60	23.5×10^{-2}	$Y = 13.467 - 5720.926X$

Table 6B. Shows the equation of the regression lines from the graphs of the percentage weight loss plotted against preservative concentration percent.

While the equation of the line indicates the slope, on which hystersis can have a marked effect; a more stable measure unaffected less by this phenonmenon would be the intercept of the two regression lines on the X axis. This means in effect, the break points of the lines which is indicative of the minimum loss in weight and hence the threshold values.

In pcf terms the threshold values are:

FUNGUS SPECIES	SPECIFIC GRAVITY	pcf
Polyporus versicolor	.45	.10267
	.60	.02976
Lenzites trabea	.45	.07254
	.60	.08742

DISCUSSION

In the interpretation of the results of this investigation, the findings of Ducan (20) should be kept in perspective. She found that the threshold values varied with the species of wood used in any such experiment.

The soil-block method, which was used in the decay tests is not without its own criticisms. There are some inherent errors involved in such a method or any method at all, that involves moisture changes or cycling in an environment with wood. The equilibrium moisture content in wood is not an exact value for any given set of conditions.

The method of evaluating the threshold values by weight loss percentage, might not be the best there is. It has an implicit assumption that the fungi involved in a decay test procedure would rot the test pieces in relative proportions to their original weight compositions. This might not necessarily be so. Other methods have been tried, these include measuring the decrease in tensile strength of the wood specimens subjected to decay; measurement of the carbon dioxide evolution or the oxygen consumption using a respirometer (40).

Thus the threshold value as a means of measuring the resistance to decay by variables incorporated in test specimens, is very subjective. Other methods have been suggested for example Merrill et al (32) working with fibre boards, used load required to pull nailhead through as an indicator. Notwithstanding the choice of test methods or the evaluation techniques, the fungus and the wood species are two other important factors that affect the results of threshold value investigations.

Moreover the number of levels used for both the preservative concentrations and nominal densities, were rather few. Thus may further preclude wide generalizations based on these results.

Bearing this in mind, the results were obtained by direct quantitative comparisons from the graphical analysis in Figures 4 to 7, which are summarized in Tables 5A and 5B.

There was a great disparity in the results obtained for Polyporus versicolor, for the nominal density of 0.60. There was a marked dissimilarity between the equation of the regression line for this nominal density level and the other levels. It had a positive slope as against the negative slopes for the others (see Figure 6). Because of these discrepancies, the values obtained for this nominal density level might be disregarded.

Threshold value has been defined by AWPA (2) or D 1413-61 ASTM (1) as "the minimum amount of preservative that is effective in preventing decay, under the conditions of the test, by a particular fungus".

The calculated threshold values, from this investigation, for Lenzites trabea fungus were $26 \times 10^{-2}\%$ and $23.5 \times 10^{-2}\%$ for the nominal specific gravity levels of 0.45 and 0.60 respectively (Figures 4 and 5). The differences between these two values can be explained by chance alone. It thus, indicates that, density variations alone was not sufficient enough to cause variations in weight loss due to decay.

The control test pieces showed a trend opposite to the treated test pieces. From this, the differences in weight loss between the two classes of density, was too great to be explained by chance. One might be led to conclude from this alone that, variations in densities, which was the only measurable variable, different for the two classes, could explain the weight loss differences. The percentage weight loss was $40.44\% \pm 10.79\%$ for the nominal specific gravity of 0.45. The comparable percentage weight loss for 0.60 nominal specific gravity was $12.82\% \pm 6.41\%$.

Moreover, direct comparisons between the percentage weight loss for the individual test pieces, at the two nominal levels of density with the same preservative level, for the two fungi involved show differences that can be explained by chance variation.

A factor that affected the results was hystersis due to the moisture cycle involved in the test methods. In the design of the experiments, it was not taken into account because with well rotted test pieces, the gain in weight due to hystersis would be minimal. What is of interest here is the break point in the regression line rather than its interception with the X axis. In the latter situation hystersis would affect the results more markedly than it would on the former. An estimate from the experiment would put its effects as between 1.2% and 1.5%; but the effects could be as large as 4% to 5%. Hystersis could have been responsible for part, if not all the gain in weight that was recorded as negative decay.

From the experience with this investigation, Lenzites trabea would be preferred for such tests. The relative lack of attack by Polyporus versicolor might have been due to its relatively poor growth on the feeder strips. A more appropriate culture method for Polyporus versicolor would have been using filter paper infiltrated with the agar and malt.

Particleboard has great potential with respect to availability of raw materials and contribution to solving the housing problems in Nigeria.

Cognizance was taken of the facts that there are other aspects of production and testing not included in this investigation. There are problems that are unanswered by this experiment, both technical and economic. Hence the necessity for further investigation into such aspects as process selection, hygroscopic shrinkage and swelling, constructional techniques, education of the users and other economic and social aspects.

CONCLUSION

From the results obtained it may be concluded, within the restrictions imposed by time scope and laboratory procedures on this investigation, that particleboard of a quality exceeding the requirements of Commercial Standard CS 236-66, can be produced from a single tropical species such as "Obeche".

It was also clear from the results of this experiment that it is possible to apply preservative treatments to such a particleboard, in order to make it resistant to fungal decay which is prevalent in the tropics.

It may be concluded, based on the evaluation in this investigation, that the threshold value i.e. the minimum concentration of pentachlorophenol needed to protect medium-density particleboard from decay by Lenzites trabea should be between 0.23% and 0.26% based on dry wood weight.

In this respect, density of the board might be a factor to consider for economic application of such a preservative. But there is no evidence to show that density is sufficiently effective enough to contribute significantly to decay resistance of such boards.

The threshold values established for the nominal specific gravity of 0.45 and 0.60 using Lenzites trabea are 0.26% and 0.23% of preservative based on the dry wood weight respectively. The only reasonable threshold value obtained from the Polyporus versicolor tests is that for the nominal specific gravity of 0.45. The value was 0.37%. In pcf terms the threshold values were 0.07 and 0.09 for Lenzites trabea and 0.1 for Polyporus versicolor. This brings out the differential action of the fungi as well as the subjectivity of the tests and the evaluation methods.

Hystersis can be an important phenomenon affecting results of evaluation of extent of decay by weight loss techniques, but values usually obtained are too small to make any practical impact on the threshold values.

APPENDICES

APPENDIX I. Data Sheet for Cascophen PB-65.

Product Name:	CASCOPHEN PB-65
Product Features:	A liquid phenol formaldehyde binder for durable particleboard. Bond conforms to ASTM Accelerated Aging Test outlined in D 1037-72.

Physical Properties (at the time of manufacture):

pH @ 25°C.	11.3 ± .1
Viscosity @ 25°C.*, cps.	300 ± 30
Specific Gravity @ 25/25°C.	1.199 ± .003
Solids, percent.	45 ± 1
Gel Time @ 121°C., minutes.	75 ± 1.0

Storage Stability (from time of manufacture):

Temperature, °F.	50	70	90	110
Life, months.	2	1	1/2	1/10

*Brookfield RVF #1/20 rpm.

Remarks: CASCOPHEN PB-65 is a fast curing resin designed for use in durable particleboard. It offers excellent durability with both hardwood and softwood furnishes. NOTE: Most phenolic resins are incompatible with wax emulsions. Wax should be applied separately rather than admixed.

APPENDIX II. Percentage of Weight Loss for Solid Wood Controls.

	S.G.		NaOPCP %	Wt. Loss %	Range
LT	.2992	.2764 - .3569	0	LT. 58.1024	43.137 - 65.934
PV	.3321	.3027 - .3634	0	PV. 15.5815	2.76 - 26.404

NOTE: Method: oven dry weight

LT: average of 5

PV: average of 4

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