RESIN-TREATED PULPBOARD CORE MATERIAL FOR SANDWICH CONSTRUCTIONS

March 1947

(No.) R1623

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
FOREST PRODUCTS LABORATORY
Madison, Wisconsin
In Cooperation with the University of Wisconsin

RESIN-TREATED PULPBOARD CORE MATERIAL FOR

SANDWICH CONSTRUCTIONS

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Abstract

Satisfactory methods were developed at the Forest Products Laboratory for uniformly impregnating, drying, and curing pulpboard for core materials for sandwich construction.

Highest strength core materials in the 0.10 to 0.20 specific gravity range were those prepared from uniformly impregnated pulpboards that contained a wide range of coarse and fine groundwood fibers and 40 to 50 percent of an oil-modified phenol resin. This type of core material resisted weathering and attack by decay organisms to a much higher degree than did balsa wood.

The strength properties of the pulpboard core material were essentially equal to the original requirements suggested by the ANC Subcommittee on Wood Aircraft Structures, August 10, 1943, but the flatwise compressive and tensile strengths were below the revised requirements set up by the AAF Materiel Command, August 19, 1944.

Introduction

The simplified structural designs, greater rigidity, and reduced weight made possible by sandwich-type constructions were believed to warrant considerable investigation directed toward the development of materials best suited for

[1]Special acknowledgement is made to J. O. Blew, Jr., H. W. Eickner, J. P. Limbach, of the Forest Products Laboratory and to C. S. Moses, Bureau of Plant Industry, Soils & Agricultural Engineering, for valuable assistance received in the preparation of this bulletin.

construction of this type. Several useful face materials such as the light metal alloys, plywood, and certain high-strength plastic laminates, are available for sandwich constructions. Balsa wood and lightweight synthetic materials, such as expanded cellulose acetate and expanded rubber, have been used as cores in sandwich constructions for aircraft. These core materials, however, leave much to be desired with respect to availability, cost, and physical properties. Although the optimum physical properties of an ideal core material have not yet been established, Army aircraft engineers have recognized certain minimum requirements necessary in core material to be considered for use in aircraft applications. These engineers have indicated the most important properties to be high modulus of rigidity and low specific gravity. The maximum for specific gravity was set at 0.20, and later lowered to 0.15. Satisfactory compressive, flexural, and tensile strengths, modulus of elasticity and modulus of rigidity were also considered basic requirements. Uniformity, durability, and low cost were other factors requiring consideration.

A resin-treated pulpboard core material satisfies these requirements in many respects. The suitability of this core material for use in sandwich constructions was demonstrated by several experimental samples made in single and double curvature as well as flat-shaped panels (figs. 1 and 2). It is believed that uniform core material of this type could be produced commercially in large quantities with only slight modification of existing manufacturing equipment.

The investigations covered by this report were conducted at the Forest Products Laboratory in cooperation with the ANC Subcommittee on Wood Aircraft Structures and were directed toward the development of resin-treated pulpboard core material having properties that would meet the desired tentative strength requirements set up by the AAF Materiel Command, August 10, 1943, and revised, August 19, 1944.

Suitable methods for impregnating the pulpboards with resin and removing resin solvents were developed. Experiments were conducted to determine the important variables and their effects on the materials produced. Core materials containing various types and mixtures of pulp fibers were prepared and tested to determine the best pulpboard composition. Commercial and experimental pulpboards were impregnated with various resins, including water-soluble, spirit-soluble, and oil-modified phenol resins, to determine the most suitable type of resin and the best proportions of resin and fiber. Preliminary tests were conducted to determine the durability of the experimental resin-impregnated pulpboard as compared with balsa wood.

The earlier experimental core materials were evaluated on the basis of edgewise compressive strength, resistance to bending, and modulus of rigidity. In accordance with the revised requirements of the AAF Materiel Command, later core materials were also evaluated on the basis of tensile strength normal to the faces. The experimental work covered by this investigation is described in this report.

Description of Basic Materials

Commercial pulpboards with a specific gravity of 0.17 were obtained from a manufacturer of insulating material. Significant directional properties due to the manufacturing process were displayed by the material. Handmade experimental pulpboards composed of aspen groundwood, cooked aspen groundwood, and foamed chemical pulp having specific gravities of 0.09 to 0.12 were secured from the same manufacturer.

Experimental pulpboards made at the Forest Products Laboratory with specific gravities ranging from 0.09 to 0.12 were composed of various proportions of coarse and fine aspen groundwood pulp, cooked aspen groundwood, kraft pulp, and mixtures of aspen groundwood and kraft pulp. These pulpboards were formed from pulp suspensions in a sheet mold approximately 12 inches square.

All experimental pulpboards produced in a sheet mold were essentially isotropic in the plane of the board by virtue of the method of forming.

Balsa wood used for comparison in the tests of durability was obtained from stock at the Laboratory and had a specific gravity of approximately 0.086.

Fifteen different resins or combinations of resins were used for impregnating the pulpboards. An additional resin (Resin M) was used in making some laminated specimens. The following resins were used:

- A -- spirit-soluble phenol resin, catalyzed.
- B -- spirit-soluble phenol resin modified in manufacture with 20 percent of a nonvolatile oil.
- C -- spirit-soluble phenol resin.
- D -- spirit-soluble phenol resin.
- E -- spirit-soluble phenol resin.
- F -- resorcinol resin.
- G -- spirit-soluble phenol resin.
- H -- water-soluble phenol resin.
- J -- mixed resin, 67 percent oil-modified, spirit-soluble phenol resin (B); 33 percent water-soluble phenol (H).
- K -- mixed resin, 67 percent oil-modified, spirit-soluble phenol resin (B); 33 percent spirit-soluble phenol (G).
- L -- phenol resin.
- M -- cold-setting urea-formaldehyde resin.
- N -- polyester styrene.
- O -- tetraethylene glycol dimethacrylite.
- P -- styrene-base resin.
- R -- vinyl butyral.

Impregnating, Drying, and Curing Procedures

Production of satisfactory resin-impregnated core materials required (1) the development of methods for uniformly distributing the resin throughout the pulpboard, (2) maintaining a uniform distribution of resin in the pulpboard while removing the solvents, and (3) a cure treatment to advance the resin to its insoluble and infusible stage.

Impregnation

Impregnation of the pulpboards was accomplished by two different methods. The first consisted of immersing the pulpboard in a dilute resin solution to obtain complete saturation, lifting the board from the bath, and forcing the excess solution out with a current of cool air. This method assured complete penetration of the pulpboards by the resin solution. The resin content, however, was difficult to control in this method, and the dilute resin solutions required for impregnation increased the migration of resin toward the surface during the drying cycle and also caused excessive loss of resin and solvent.

The second method consisted of applying a definite amount of resin solution to the pulpboard and allowing it to diffuse through the pulpboard in a closed chamber until a uniform distribution of the resin was obtained. In this method, the exact amount of resin required to produce the desired density was diluted with the minimum amount of solvent required to distribute the resin throughout the pulpboard. This solution was then uniformly applied to one surface of the pulpboard by means of a spray or shower or by placing the board on a film of the solution in a level tray (figs. 3 and 4). The treated board was then placed, treated side up, in a closed chamber to permit the solution to diffuse uniformly throughout the pulpboard without appreciable loss of the solvent. Impregnation with moderate amounts of phenol resin (35 to 50 percent of the weight of the finished board) required a ratio of solution to pulp of about 2 or 3 to 1, by weight. Impregnation of pulpboards with larger amounts of phenol resin or with other more viscous types of resin required higher ratios to insure satisfactory resin distribution.

Drying

Since ordinary kiln drying methods caused excessive migration of the resins, it was necessary to devise special drying methods for removing the solvent from the treated pulpboards. In one method, the migration of resin was minimized by supporting the treated pulpboard in an enclosed frame and passing a current of warm air through it alternately in one direction and then in the other. Although this method was effective in most instances, it required a large volume of warm air and did not entirely stop resin migration in pulpboards that had irregular fiber formations. A simpler method, which was used in most of these investigations, allowed the solvent to evaporate slowly from alternate sides of the treated pulpboards at room temperature. This was accomplished by placing the treated pulpboard on a partially enclosed, nonabsorbing surface and inverting it at regular intervals (fig. 5). After the amount of solvent remaining in the boards was reduced to about 10 percent, the drying was completed in a kiln at about 140° F.

Curing

The final cure of the resin-impregnated pulpboards was accomplished by placing them between the platens of a hot press (fig. 6). Accurate thickness and densities were obtained by the use of stops in the press. The temperatures recommended for curing paper laminates made with the same resins were used in general for the pulpboards; additional time was allowed, however, for thorough heat penetration. A heating period of 45 to 60 minutes at 160° C. was generally satisfactory for curing the phenol resins.

Effect of Variations in the Preparation of Core Materials on Strength Properties

Effect of Various Methods of Impregnation, Drying, and Curing

In order to compare the effect of various resin impregnating and drying methods on the strength of the final core material, aspen groundwood pulpboards of the same composition were treated as previously described, namely, by (1) immersing in the resin solution, blowing out the excess solution with cool air, and drying with a current of warm air; (2) diffusing the desired amount of resin solution into the pulpboard and drying in a current of warm air; and (3) diffusing the desired amount of resin solution into the pulpboard and drying by exposing alternate surfaces to the air. All of these treated pulpboards were then cured as described in the preceding paragraphs and shown in figure 6. The mechanical properties of these core materials, determined according to the procedures described in Appendix A, and given in table 1 show that the results obtained from the three variations in treatment were not greatly different.

Effect of Concentration of Resin Solution

Typical strength values of aspen groundwood pulpboards treated with various resin concentrations of from 21 to 33 percent by application of exact amounts and dried with a current of warm air are given in table 2. Except for plate shear values, which increased with increasing dilution of the impregnating solution, the concentrations of the resin solution used in this study for treating the pulpboards did not have a significant effect on the strength of the resulting core materials.

Effect of Curing Temperature

Core materials containing oil-modified phenol resin were cured at 160° and 175° C. for a period of 45 to 60 minutes, depending on the thickness of the core. Under these conditions the pulpboard apparently remained somewhat thermoplastic. The data given in table 3, however, show that the strength values were not improved by using the higher cure temperature.

Suitability of Various Resins

Experiments involving commercial and laboratory pulpboards treated with resorcinol, water-soluble phenol, and various spirit-soluble phenol resins were made to determine the suitability of the resins and their effect on the properties of the core material. Pulpboards treated with a phenol resin modified with 20 percent of a nonvolatile oil Resin B produced some of the highest strength properties obtained. The mixed resins, J and K, gave results similar to Resin B in the experimental pulpboards. The results of these tests are given in table 4. The specific gravity of all the commercial pulpboards was above the maximum set by the AAF Materiel Command and the ANC Subcommittee for aircraft.

In other experiments, aspen groundwood pulpboards were treated with contact-type resins including Resins N, O, P, and R. These resins were not found to be suitable because of the poor quality of the board obtained, and data are not included in table 4. Inhibition of cure in the presence of air and the excessive amounts of solvent required to obtain adequate resin distribution were factors contributing to these results.

Effect of Resin Content

Experimental aspen groundwood pulpboards were treated with various amounts of an oil-modified phenol resin (Resin B) to produce final resin contents in the cores of 47, 42, 38, and 33 percent of the total weight of the pulpboard when dry. During the curing cycle, these treated pulpboards were compressed to different degrees to produce material having equal specific gravity (about 0.20). The highest specific edgewise compression, flexure, and plate shear values were obtained in the cores that contained about 42 percent of resin and that were compressed about 22 percent. The specific flatwise tensile strength, however, increased approximately in proportion to the resin content. Test data obtained in these experiments are given in table 5, series A.

Other experiments included aspen groundwood pulpboards treated with 35, 46, and 53 percent of oil-modified phenol resin and compressed equally (8 percent) to produce specific gravities of 0.14, 0.17, and 0.20, respectively. Except for the modulus of rigidity, the specific strength properties, particularly the specific tensile strength, of these core materials increased in proportion to the resin content, as shown in table 5, series B. This indicates that the specific flatwise tensile strength is increased by increasing the resin content but is less affected by the specific gravity or the amount the board is compressed. The effect of density or specific gravity on strength is also shown in this test series. All the specific strength properties, except modulus of rigidity, were highest at the highest resin content, (53 percent) at which the specific gravity was also highest (0.20). In the preceding test series, when the pulpboards were compressed different amounts to bring them all to a specific gravity of 0.20, the optimum resin content was 42 percent.

Effect of Composition and Structure of Pulpboards

In preliminary experiments it was found that the densities of most of the commercial insulating pulpboards were too high. Consequently, when they were impregnated with amounts of resin required for the best strength properties, the resulting core materials were above the maximum density permitted by ANC requirements. Therefore, a sheet mold was constructed (fig. 7) in which small (10- by 10- by 1/2-inch) experimental pulpboards, with specific gravities in the range of 0.09 to 0.12, were prepared. Larger panels of experimental pulpboards (4 by 4 feet) in the same specific gravity range were obtained from a commercial source. Resin-impregnated pulpboard core materials were prepared with different pulpwoods of varied fiber sizes to determine suitable pulp types, fiber sizes, and formations necessary to produce core materials with the highest strength within the density range required. Addition of kraft fiber in amounts from 10 to 40 percent to aspen groundwood was tested for effect of kraft fibers on strength.

The strength properties of core materials prepared by impregnating aspen groundwood, cooked aspen groundwood, and foamed chemical fiber pulpboards are given in table 6. These results show that the highest strength values were obtained with the comparatively stiff aspen groundwood pulp, though none of the pulpboards met the ANC minimum requirements in all properties. Resin content of about 40 percent seemed to be the optimum.

Experimental pulpboards composed of kraft fibers alone were too dense to permit impregnation with substantial amounts of resin. Pulpboards composed of mixtures of screened aspen groundwood and up to 40 percent of kraft fiber and impregnated with 40 percent of phenol resin had specific gravities between 0.20 and 0.21. It is shown in table 7 that the strength properties of these materials were improved in proportion to the amount of kraft fiber used, though the difference between results with 30 and 40 percent kraft was not so great.

Low-density pulpboards were prepared from aggregates of aspen groundwood pulp passing screens of various sizes and also from mixtures of a coarse-screened groundwood with up to 42 percent of a paper-making grade of groundwood. The increase in density of pulpboards produced by the addition of fine fibers limited the amount of paper-making groundwood that could be used. These pulpboards were treated with phenol resin.

The strength values obtained on the core materials prepared with various screen fractions of the pulp are given in table 8. These results show that very low strengths were obtained with coarse fibers alone (40- to 20-cut) and that the strength of core materials improved with increasing fineness of the fiber aggregate. Pulpboards made with whole stock had higher compression strength values than those made with uniform pulp, either coarse or fine or specific mixtures of coarse and fine. The addition of fine fibers to coarse fiber aggregate pulp up to 25 to 30 percent also improved the pulpboard strengths, as shown in table 9. In other experiments, it was found that the removal of extremely large splinters from the groundwood pulp reduced the spread in test values between individual boards but did not change the average strength values.

The methods used to prepare both the commercial and experimental pulpboards produced a high degree of orientation of fibers in a plane parallel to the faces, as shown in figure 8. This orientation of fibers was also shown by the fact that ultimate edgewise tensile strengths were 175 to 265 pounds per square inch, whereas ultimate flatwise tensile strengths of typical core materials were 35 to 50 pounds per square inch. These strength values were reversed in laminated pulpboard core materials prepared by cutting the dry, resin-treated pulpboards into strips of suitable width and clamping them together, face to face (fig. 2), using various bonding methods. The flatwise tensile strengths of these laminated boards, given in table 10, are approximately the same as the edgewise tensile strengths of the original boards.

Strength Requirements for Core Materials

Tentative strength requirements for core materials as suggested by the ANC Subcommittee on Wood Aircraft Structures, August 10, 1943, are given in table 2. Also shown in this table, the board treated with a 21 percent resin solution fulfilled the density requirement and exceeded the compressive strength, modulus of rupture, and modulus of rigidity requirements, but had 88 percent of the required modulus of elasticity in bending. Therefore, it is indicated that the strength requirements of the ANC Subcommittee on Wood Aircraft Structures were essentially met by this board.

The AAF Materiel Command, revised their tentative standards for properties of core materials on August 19, 1944. The revised minimum properties included: a specific gravity in the range of 0.05 to 0.15, specific flatwise tensile strength[2] of 2,000, specific flatwise compressive strength of 1,000, and specific modulus of rigidity of 40,000. Although the resin-impregnated core materials in general exceeded the modulus of rigidity requirement by approximately 50 to 200 percent, their flatwise tensile strength was only about one-tenth of that required. Reorientation of the fiber structure of the core materials by face-to-face lamination increased their flatwise tensile strength to about 75 percent of the required value at 0.18 specific gravity and to about 60 percent of the required value at 0.16 specific gravity, as shown in table 10. On the basis of these results it is not considered likely that the revised tensile strength and density requirements can be met by further improvements in the materials or methods used in the preparation of resin-impregnated pulpboards.

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[2] Strength values derived by dividing strength in pounds per square inch by the specific gravity of the material.

Durability of Experimental Pulpboard Core Material

At the request of the ANC Subcommittee on Wood Aircraft Structures, exploratory tests were made to determine the resistance of resin-impregnated pulpboards, as compared with balsa wood, to some of the conditions to which they might be exposed in actual service. These tests included exposure to cycles of high and normal temperatures, exposure to cycles of high and normal humidities, continued exposure to moist soil, continued exposure to wood-destroying organisms, and exposure to outdoor atmospheric conditions such as prevail in Madison, Wisconsin. The material selected for these tests was made with aspen groundwood pulpboard treated with approximately 50 percent phenol resin (Resin B).

The results of the four phases of the durability tests are given in the following discussion and in Appendix B. In general, the resin-impregnated pulpboards were found to retain their original properties under severe exposure conditions longer than balsa.

Temperature and Humidity Cycle Tests

The actual conditions of the temperature and humidity cycles and the percent change with respect to the initial values of core materials retained at two midcycles and two complete cycles are given in table 11. With respect to resistance to high temperature, the pulpboard was equal to balsa in retaining its strength, distinctly better in weight fluctuation, and slightly better in dimensional stability.

The exposure of pulpboard cores to cycles of high and moderate humidities produced a lower strength loss but a slower recovery of original strength than in balsa, probably because of a lower rate of absorption and loss of moisture. Pulpboard cores showed less weight fluctuation and slightly better dimensional stability than balsa under these conditions.

Soil Exposure Tests

In the soil exposure test a number of specimens of balsa and pulpboard cores, approximately 3/8 by 4 by 12 inches, were placed vertically in the ground to about one-half of their length at Madison, Wisconsin. One duplicate set of specimens of each material had cut edges of the specimens protected by coating with white lead and two coats of aluminum paint.

Examination of the soil test specimens at the end of 1 month's exposure showed considerable softening and some appearance of decay below ground in the unprotected balsa due principally to moisture absorption. The unprotected pulpboard cores showed no appreciable weakening or tendency to break down but did show some softening due to moisture. The condition of edge-protected specimens of both materials was somewhat better than that of the unprotected specimens, as shown by less softening, especially near the edges.

At the end of 3 months' exposure to soil, all the specimens of balsa wood showed considerable decay at the ground line and were considered unserviceable. At the same time, the specimens of pulpboard core were softened by moisture, and several broke off when light pressure was applied. No centralized softening due to decay was observed, and cross sections of broken specimens indicated a sound condition. No difference in the specimens with and without edge protection was observed.

Exposure to Wood-destroying Organisms

In the test of resistance to wood-destroying organisms, duplicate sets of 3/8- by 1- by 2-inch specimens of pulpboard core material with and without protection of cut edges and similar duplicate sets of specimens of balsa wood were exposed at room temperatures to various micro-organisms in bottle-type tests. Details of the conditions and results of these tests are given in Appendix B, table 12. The average weight losses sustained by the specimens under the various exposure conditions indicated that the pulpboard core material was considerably more resistant than balsa wood to wood decay organisms.

Natural Weathering Exposure Tests

Two specimens of pulpboard core material and of balsa wood, each with and without edges protected, were exposed to natural weathering on the test rack on the roof of the Laboratory building (figs. 9, 10, and 11). After an outdoor-exposure period of 6 months the pulpboard appeared sound but was dark in color and slightly cupped. After the same exposure the balsa specimens were sharply warped and appeared pithy and light in color and were much softer than the pulpboard cores. After 21 months' exposure, the pulpboard still appeared sound and only slightly warped, while the balsa wood was very badly weathered (figs. 9, 10, and 11).

Conclusions

The conclusions reached as a result of these investigations are:

(1) Core materials having the highest strength properties were prepared from pulpboards that contained a wide range of coarse and fine groundwood fibers uniformly impregnated with from 40 to 50 percent of an oil-modified phenol resin developed, in general, the better properties.

(2) The proper proportion of the different fiber sizes and orientations of the fibers in the pulpboards is more important than the type of phenol resin in producing high-strength core materials.

(3) The resin-impregnated pulpboard is distinctly superior to balsa wood in resistance to decay organisms, moisture absorption, and dimensional stability at high humidities, and is equal to balsa in weight and dimensional stability at high temperature. The loss in strength of pulpboard core materials is not so rapid as the loss of strength of balsa when exposed to severe conditions, such as contact with moist soil or extended exposure to natural weathering.

(4) Some further improvement in the strength and durability of resin-impregnated pulpboards may be possible; it does not appear likely, however, that the flatwise tensile and compressive strength requirements of the AAF Materiel Command will be met by modifications of the present materials and procedures.

APPENDIX A

STRENGTH TESTS

Preparation of Test Specimens

Pulpboard and balsa panels exposed to cycles of elevated and normal temperatures and those exposed to cycles of high and normal humidity were conditioned for 96 hours at 75° F. and 65 percent relative humidity prior to test. All other test panels were stored at normal room temperature and humidity, following preparation, and tested within 48 hours without preconditioning.

In general, pulpboard panels were first trimmed to provide specimens ranging from 9 to 11-1/2 inches square, for modulus of rigidity tests. The ratio of length of edge to thickness was about 25 to 1. After obtaining shear modulus data, four full length strips were cut from the central portion of each panel to provide flexure, compression, and tension specimens as follows: two strips, each 1 inch wide for flexure; one strip, 1 inch wide, to provide two compression specimens, each 1 by 4 inches by original or molded thickness (t); and one strip, 1-1/2 inches wide, to provide five flatwise tensile specimens.

Flatwise tension tests were made on dumbbell-shaped specimens in the standard tensile grips used for molded plastic specimens. These specimens were prepared by gluing wood strips to each face of a 1-1/2-inch strip of pulpboard, employing pressures of 10 pounds per square inch or less, in order to prevent damage to the pulpboard. Test specimens having a 1- by 1-inch net section were then cut to shape on a band saw.

Testing Procedure

Mechanical tests were conducted in accordance with procedures described in Forest Products Laboratory Report No. 1555 entitled "Tentative Methods of Test for Determining Strength Properties of Core Material for Sandwich Construction," February 1946, or as otherwise described.

All specimens, except panels exposed to cycles of high and normal temperatures and humidities, were tested under ordinary room conditions without preconditioning. No determinations of moisture content were made, and specific gravities as given are based on weight and volume at test and include whatever moisture was present.

Specific gravity values were, in general, determined from the weight and volume of the trimmed panels prior to conducting the plate shear test. In a few instances, where surface imperfections precluded the usefulness of the whole panel, specific gravities were determined from the test weight and volume of flexure specimens cut from the usable portions of such panels.

Modulus of Rigidity Tests

Modulus of rigidity data were obtained by means of the Forest Products Laboratory plate shear test, developed for measuring the shearing moduli in wood.[3] Load was applied to the surface of the material in curing-pressure direction. The modulus of rigidity as determined by this method is the same in all directions if the material is isotropic. Since sheet-molded pulpboards are virtually isotropic in the plane of the thickness only, the modulus determined in these flatwise tests is the modulus associated with shear distortions in planes parallel to the faces of the panel. Test specimens were 9 to 11-1/2 inches square by 3/8 to 1/2 inch thick, the full (sheet-molded) thickness.

Edgewise Compression Tests

Edgewise compression tests were conducted on 1- by 4-inch specimens of the material, with load applied on the machined edges of the pulpboard, that is, in a direction perpendicular to that of the curing pressure direction. Specimens were tested as laterally supported columns in a hydraulic testing machine at a uniform rate of loading of 0.012 inch per minute. A 2-inch gage length Martin's mirror compressometer was used to supply the deformation data.

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[3] "Method of Measuring the Shearing Moduli in Wood," Forest Products Laboratory Report No. 1301, June 1944.

Flexure Tests (Modulus of Elasticity)

Flexure specimens 1 inch wide by (t) by 9 to 11-1/2 inches long, were tested flatwise as a simple beam with center loading, over spans equal to 16 times the thickness of the material (6 to 8 inches). A few of the low-density flexure specimens were 1-1/2 inches wide. Center deflections were obtained by means of a 0.001-inch dial gage. Tests were conducted in a universal testing machine equipped with a scale for weighing load, and operated at no-load speeds of 0.024 to 0.028 inch per minute. All specimens were so positioned over supports that areas of noticeable irregularity would not fall at or near the center of span.

Two lengthwise and two crosswise flexure specimens were tested from a number of experimental pulpboards to investigate the directional effect. Differences in modulus of rupture of from 0 to 10 percent resulted among specimens for a given direction, as well as between specimens from each direction. Resulting differences between directions, however, did not favor any one direction. These tests served to confirm the virtual isotrophy of the experimental pulpboards in the plane of the thickness, and to indicate the degree of variability of the materials as manufactured.

Definite directional properties were indicated for the commercial pulpboards reported in table 4. For these boards, the lengthwise (machine direction) moduli of rupture were from 20 to 40 percent greater than the crosswise moduli. The reported compressive and flexural properties of these commercial boards represent the average values for two lengthwise and two crosswise tests of each material.

Tension Tests

All flatwise tension specimens were dumbbell-shaped specimens having a 1- by 1-inch net section. These specimens were tested for maximum load only, at a uniform rate of loading of about 0.05 inch per minute. All reported values of ultimate tensile strength represent the average of four to six specimens tested normal to the plane of the faces, except the values of the laminated pulpboards reported in table 10. While these laminated specimens were identical to the normal specimens in size, shape, and number, their fiber orientation was such that the reported tensile strength was analogous to the edgewise tensile strength of the original material plus the strength of the adhesive material used in laminating.

APPENDIX B

DECAY RESISTANCE OF BALSA AND PULPBOARD CORE MATERIALS

By

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Introduction

Durability tests on balsa and pulpboard core materials were made as part of a Forest Products Laboratory research program on the characteristics of several core materials for sandwich constructions. Most of the exposure tests selected for this program were designed to duplicate insofar as possible conditions that might be found in aircraft uses of such materials. Although any accelerated laboratory decay test is likely to expose the samples to more severe conditions than generally are met with in use, it should be possible to compare the relative durability of the various materials by the percentages of weight lost during exposure to fungus attack. This was done in a preliminary way and the results are discussed in this report.

Materials

The test materials were the following:

Pulpboard

Code	Pulp Percent	Resin Percent	Specific gravity
2081-38	60	40	0.22
2081-43	61	39	.21
2081-44	62	38	.21

[4] In cooperation with the Forest Products Laboratory, maintained by the Forest Service, United States Department of Agriculture, at Madison, Wis., in cooperation with the University of Wisconsin.

The pulpboards were from the same 4- by 4-foot panel and contained aspen groundwood passed through a 40-cut screen (slots 0.040 inch wide).

The resin (Resin B) was a spirit-soluble phenolic resin modified in manufacture with 20 percent of a nonvolatile oil.

Balsa

The balsa specimens were taken from three panels, each of which was constructed of three strips of balsa, edge-glued with a resorcinol glue. The balsa was so selected that the specific gravity of each panel was approximately 0.086.

Aspen

The aspen control specimens were taken from the sapwood of a pulp log of *Populus* sp.

Test specimens 1 by 2 inches were cut from all this material. For the wood samples, the grain direction was perpendicular to the long axis of the specimens. The balsa specimens were cut so as to avoid any glue lines. In the use of core materials it is assumed that they are adequately protected along the edges against entrance of moisture and decay organisms. Therefore, in this test, one-half of the specimens were edge-treated. This treatment consisted of one coat of white lead followed after a drying interval by two coats of aluminum varnish. The aluminum varnish was mixed in the proportion of 1-1/2 pounds of aluminum paste, fine aircraft grade, to 1 gallon of phenolic resin varnish.

Fungi used were *Poria incrassata*, *P. microspora*, brown-rot fungi, and *Polyporus versicolor*, a white-rot fungus.

Method

All specimens were conditioned at 80° F. and 65 percent relative humidity for 14 days until they were in approximate equilibrium. During this period the edge treatment was applied to the specimens designated. The equilibrium weight of all specimens was recorded both before and after the edge treatment.

The test specimens were surface-disinfected by exposure to an oven temperature of 60° C. for 3 hours.

The test specimens were added to pure cultures of the fungi growing on a substrate of 1.5 percent malt agar in 6-ounce French square bottles. Glass rods 0.140 inch in diameter were used to keep the specimens from direct contact with the substrate. Other test specimens were buried for one-half to two-thirds their length in potting soil inoculated with Polyporus versicolor. All cultures were incubated at room temperature.

The test specimens were exposed for periods of 1 and 3 months. They were weighed and examined immediately after removal from exposure.

The specimens were reconditioned at 80° F. and 65 percent relative humidity. They were in approximate equilibrium in from 1 to 3 months, and final weights were recorded. A few of the specimens were also dried in an oven at 103° C.

The percentage loss in weight, based on the approximate equilibrium weight at 80° F. and 65 percent relative humidity was computed. Where specimens were edge treated, the weight of the coatings was subtracted before the computations were made.

All specimens were examined and notes made on their condition.

Results

The average loss in weight of the test specimens is given in table 12. From these data, the following observations may be made:

Aspen Wood Controls

The aspen wood controls were attacked by all fungi to a signficant extent even in 1 month. The greatest average weight loss, 74.7 percent, was sustained by the samples placed for 3 months in soil inoculated with Polyporus versicolor. Evidently the fungus cultures and the conditions under which they were incubated were conducive to good development.

Balsa

In 1 month of testing only those specimens of balsa exposed to Polyporus versicolor showed significant weight losses. Many of these specimens were visibly decayed. After 3 months of exposure, significant weight loss and visible decay were caused by all fungi. Even specimens that lost little weight usually had a few visible spots of decay.

Losses in the edge-treated specimens exceeded those of the plain specimens in all exposures, except in the inoculated soil where the weight loss was considerably less. The amount of weight loss was, in general, confirmed by macroscopic examination and handling of the specimen.

Pulpboard

After 1 month, only specimens of pulpboard exposed to Poria microspora showed a loss, and this was only 3.6 percent. At the end of 3 months this fungus was still the only one causing consequential weight loss, although P. incrassata caused some loss. Test specimens differed visibly from reference specimens only in being somewhat darker. When compressed, however, the test specimens were somewhat spongy, depending on the amount of weight loss they had sustained. The external shell of the specimens seemed more or less intact, except for a few soft spots in the edges of untreated samples.

The average weight losses in the specimens with sealed edges were about twice those of the untreated specimens. This difference was not evident when the specimens were compressed between the fingers, but more of the specimens with sealed edges could be compressed.

Moisture content determinations were not made for all the specimens in the test because of the uncertain effect of high temperature on pulpboard and samples that had received an edge treatment. At the end of 1 month, it could be stated that the average moisture content of all test specimens was above 30 percent.

Discussion

The computation method adopted for this test was used to avoid errors that might arise from losses of the edge coating during oven drying. It appears that this may amount to 2 or 3 percent. On the other hand, edge-treated reference specimens maintained at 80° F. and 65 percent relative humidity for 6 months showed but little change in weight. Furthermore, the initial equilibrium moisture content of the balsa specimens varied from 8 to 13 percent. The use of reference samples to compute the weight of the specimens on an oven-dry basis would result in considerable error. It was felt that the method used was the best one under the circumstances.

Under the conditions of this test, therefore, the average values show that pulpboard core material is several times as resistant to decay as balsa. It is also apparent that fungi are very specific in their attack on these two materials. Practically, these materials when used in construction might be exposed to infection from all these fungi and even many others that might cause even greater weight losses. The present comparison, however, gives a basis on which durability of the materials may be evaluated.

The considerable weight losses registered by a few individual pulpboard specimens when attacked by Poria microspora should be further evaluated by strength tests. In observing and handling these specimens, they appear to be less affected than balsa specimens of considerably less weight loss.

It should be mentioned that contaminating fungi appeared in a number of the cultures during the first month of exposure. Aspergillus sp. was the one commonly encountered. This contamination was probably due to the fact that the samples were not exposed long enough at 60° C. Comparison of the weight losses of specimens on pure cultures, however, results in the conclusion that this inadvertent contamination by Aspergillus sp. did not greatly influence the experiment. If the presence of the contamination did slow up the attack of the decay fungi, it would tend to broaden the differences shown in this test, since most of the contamination was confined to the balsa specimens.

The greater weight loss suffered by the edge-treated specimens tested in bottles is rather puzzling. Because visual examination tends to support these weight losses, it does not appear that these results are errors due to the reaction of the coatings during the test. Perhaps the difference is due to a more favorable moisture content of the sealed specimens. A factor that should not be ignored in future investigations is the possible stimulation of fungus growth as a result of the aluminum used in the edge treatment of the specimens. It should be noted that the weight losses of the soil-exposed specimens were greater for the untreated samples.

For comparative purposes at this time it is best to use the figures for the untreated material.

Table 1.--Effect of various methods of resin-treating and drying on properties of pulpwood core material composed of aspen groundwood and Resin B

Impregnating and drying method	Resin content	Specific gravity	Compression, edgewise[1]		Flexure, flatwise[1]		Forest Products Laboratory plate shear -- modulus of rigidity[1]
			Ultimate strength	Modulus of elasticity	Modulus of rupture	Modulus of elasticity	
	Percent		P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.
Immersed[2] and blown[3]	44.4	0.19	1,830	308,000	2,480	242,000	128,000
Diffused[4] and blown[3]	46.3	.19	1,840	318,000	2,500	264,000	117,000
Diffused[4] and air-dried[5]	50.0	.20	1,540	281,000	2,370	305,000	117,500

[1] Average absolute properties divided by specific gravity.

[2] Impregnated by complete immersion in resin solution and blowing out excess solution with cool air.

[3] Dried by blowing warm air through the pulpboard.

[4] Impregnated by diffusing the required amount of resin throughout the pulpboard.

[5] Dried by exposing the surfaces to the atmosphere, alternating the exposed surface at regular intervals.

Table 2.--Effect of concentration of resin-impregnating solution on the strength of pulpboard core material composed of aspen groundwood and Resin B[1]

Concentration of resin solution	Resin content	Specific gravity	Compression, edgewise[2]		Flexure, flatwise[2]		Forest Products Laboratory plate shear -- modulus of rigidity[2]
			Ultimate strength	Modulus of elasticity	Modulus of rupture	Modulus of elasticity	
Percent	Percent		P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.
33	46.0	0.19	1,800	308,000	2,300	245,000	107,000
28	46.5	.19	1,870	317,000	2,500	274,000	112,000
24	46.5	.19	1,770	300,000	2,800	264,000	122,000
21	46.3	.19	1,910	347,000	2,420	272,000	125,000
Minimum ANC Goals[3]							
	....	.20	1,270	310,000	1,900	310,000	115,000

[1]Impregnated by diffusing the required amount of resin throughout the pulpboard and dried by blowing warm air through the pulpboard.

[2]Average absolute properties divided by specific gravity.

[3]Tentative strength standards set up by the ANC Subcommittee on Wood Aircraft Structures, August 10, 1943.

Table 3.--Effect of temperature of cure on the properties of pulpboard core material composed of aspen groundwood and Resin B

Curing temperature[1]	Resin content	Specific gravity	Compression, edgewise[2]: Ultimate strength	Compression, edgewise[2]: Modulus of elasticity	Flexure, flatwise[2]: Modulus of rupture	Flexure, flatwise[2]: Modulus of elasticity	Tension, flatwise[2]: Ultimate strength	Forest Products Laboratory plate shear -- modulus of rigidity[2]
° C.	Percent		P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.
160	50	0.21	1,420	223,000	2,210	232,000	169	105,000
175	50	.21	1,390	216,500	2,050	200,000	132	98,000

[1] Cured 45 minutes.

[2] Average absolute properties divided by specific gravity.

Table 4.--Properties of pulpboard core materials treated with various resins

Resin	Resin content	Specific gravity	Compression, edgewise[1]: Ultimate strength	Compression, edgewise[1]: Modulus of elasticity	Flexure, flatwise[1]: Modulus of rupture	Flexure, flatwise[1]: Modulus of elasticity	Tension flatwise[1]: Ultimate strength	Forest Products Laboratory plate shear -- modulus of rigidity[2]
	Percent		P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.
				Commercial Pulpboard[2]				
A	53.2	0.38	2,510	390,000	2,140	432,000	....	170,000
B	50.5	.37	2,730	390,000	3,570	426,000	....	168,000
C	51.0	.39	570	93,000	920	55,600	....	22,890
D	52.1	.35	1,510	287,000	2,360	372,000	....	156,000
E	52.3	.34	1,710	323,000	2,140	328,000	....	135,000
F	52.5	.36	2,880	381,000	4,010	497,000	....	157,100
				Experimental Pulpboard[3]				
G	43.8	.19	1,430	299,000	2,110	267,500	204	110,800
H	44.5	.19	1,180	251,000	2,430	289,000	165	128,000
B	45.9	.19	1,800	312,000	2,400	256,000	225	118,000
J	45.0	.20	1,900	285,000	2,800	293,000	220	124,000
K	47.5	.20	1,720	303,000	2,370	274,000	260	127,000

[1] Average absolute properties divided by specific gravity.

[2] Specific gravity before resin-impregnation, 0.17.

[3] Specific gravity before resin-impregnation, 0.09. This pulpboard was supplied by a manufacturer of insulating board.

Table 5.--Effect of resin content on strength properties of pulpboard core material composed of aspen groundwood and Resin B

Resin content	Compression	Specific gravity	Compression, edgewise[1]		Flexure, flatwise[1]		Tension	Forest Products Laboratory plate shear -- modulus of rigidity[1]
			Ultimate strength	Modulus of elasticity	Modulus of rupture	Modulus of elasticity	Ultimate strength	
Percent	Percent		P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.
		Series A, Different degrees of compression during cure						
47	17	0.20	940	154,000	1,450	175,500	150	97,200
42	22	.20	1,130	206,000	1,915	288,000	103	115,000
38	25	.20	945	182,000	1,630	198,000	100	97,000
33	29	.20	970	177,000	1,990	236,000	73	106,000
		Series B, Equal Compression During Cure						
53	8	.20	1,085	198,000	1,865	235,000	217	68,000
46	8	.17	865	131,500	1,645	184,000	150	100,000
35	8	.14	795	131,000	1,205	121,000	114	67,000

[1]Average absolute properties divided by specific gravity.

Table 6.--Properties of pulpboard core material made of three types of pulpboard treated with various amounts of Resin B

Resin content	Specific gravity	Compression, edgewise[1]: Ultimate strength	Compression, edgewise[1]: Modulus of elasticity	Flexure, flatwise[1]: Modulus of rupture	Flexure, flatwise[1]: Modulus of elasticity	Forest Products Laboratory plate shear -- modulus of rigidity[1]
Percent		P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.
			Cooked aspen groundwood			
17	0.19	880	226,000	1,090	166,000	81,000
31	.18	990	275,000	1,790	212,000	100,000
52	.19	1,140	284,000	1,130	153,000	76,000
			Aspen groundwood			
21	.19	1,010	344,000	1,700	242,000	107,000
40	.20	1,370	348,000	2,230	267,000	110,400
58	.19	980	244,000	1,100	120,000	77,000
			Foamed chemical pulp			
14	.19	1,500	243,000	2,870	245,000	....
38	.19	1,320	256,000	1,960	224,000	....
59	.19	1,290	249,000	1,180	181,000	....

[1] Average absolute properties divided by specific gravity.

Table 7.--Specific strengths of cores made with pulpboards composed of kraft-groundwood mixtures and Resin B

Composition of board	Resin content	Specific gravity	Compression, edgewise[1]: Ultimate strength	Compression, edgewise[1]: Modulus of elasticity	Tension, flatwise[1]: Ultimate strength	Flexure, flatwise[1]: Modulus of rupture	Flexure, flatwise[1]: Modulus of elasticity	Forest Products Laboratory plate shear -- modulus of rigidity[1]
Percent	Percent		P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.
Kraft-0 Groundwood-100	41.0	0.20	755	160,000	55	1,410	254,000	96,000
Kraft-10 Groundwood-90	41.5	.21	870	181,500	45	1,670	226,000	108,000
Kraft-20 Groundwood-80	40.5	.20	890	193,000	56	1,940	216,000	103,000
Kraft-30 Groundwood-70	40.0	.21	1,010	233,000	70	2,110	232,500	121,000
Kraft-40 Groundwood-60	40.0	.21	1,030	216,000	82	2,300	252,000	115,500

[1] Average absolute properties divided by specific gravity.

Table 8.--Effect of using aggregates of various sizes of screened aspen groundwood in pulpboards on the properties of pulpboard core material[1]

Composition of boards	Resin content[2]	Specific gravity	Compression, edgewise[3]: Ultimate strength	Compression, edgewise[3]: Modulus of elasticity	Flexure, flatwise[3]: Modulus of rupture	Flexure, flatwise[3]: Modulus of elasticity
	Percent		P.s.i.	P.s.i.	P.s.i.	P.s.i.
Whole stock	43	0.19	1,530	400,000	1,720	215,000
40- to 20-cut pulp[4]	45	.18	890	203,000	1,110	150,000
20- to 8-cut pulp[4]	41	.18	1,260	254,000	1,750	215,000
8-cut to 200-mesh pulp[4]	45	.18	1,420	263,000	2,240	215,000

[1]Prepared by immersing in the resin solution, blowing out the excess resin, then drying by blowing warm air through the board.

[2]Resin B was used.

[3]Average absolute properties divided by specific gravity.

[4]Pulp retained between screen plates of the indicated size.

Table 9.--Effect of various mixtures of fine and coarse aspen groundwood on the properties of pulpboard core material, using two resins

Mixture of aspen groundwood: Coarse[2]	Mixture of aspen groundwood: Fine[3]	Resin content	Specific gravity	Compression, edgewise[1]: Ultimate strength	Compression, edgewise[1]: Modulus of elasticity	Flexure, flatwise[1]: Modulus of rupture	Flexure, flatwise[1]: Modulus of elasticity	Tension flatwise[1]: Ultimate strength	Forest Products Laboratory plate shear -- modulus of rigidity[1]
Percent	Percent	Percent		P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.
					Resin B				
100	0	43	0.19	750	123,000	1,280	154,000	77	85,000
74	26	37	.19	1,290	222,000	2,170	276,000	127	122,000
58	42	25	.20	1,200	186,000	2,200	242,000	105	114,000
					Resin L				
100	0	39	.19	680	173,000	1,300	249,000	26	86,000
90	10	40	.20	1,050	184,000	1,400	241,000	76	110,000
80	20	40	.20	1,350	250,000	1,990	301,000	120	139,000
70	30	39	.19	1,270	212,000	2,020	268,000	192	112,000

[1] Average absolute properties divided by specific gravity.

[2] As used in insulating boards.

[3] Paper-making quality.

Table 10.--Flatwise tensile strength of face to face laminated pulpboard core material of aspen groundwood with Resin B

Board number	Specific gravity	Resin content	Flatwise tensile strength	
			Ultimate	Ultimate ÷ specific gravity
		Percent	P.s.i.	P.s.i.
[1]CP-2099-7X	0.19	50.0	270	1,420
[2]CP-2111-15X	.22	48.7	240	1,090
[3]CP-2165-5	.16	40.0	160	1,000
[4]CP-2165-7	.16	40.0	200	1,250

[1]Self-bonded by the resin in the board.

[2]Bonded with cold-setting Resin M.

[3]Self-bonded by the resin in the board (uniform resin distribution in pulpboards impregnated by diffusion and air dried).

[4]Self-bonded by the resin in the board (resin concentrated at joints in pulpboards impregnated by diffusion and kiln dried to concentrate the resin at the surface before laminating).

Table 11.--Percent of change in properties of balsa and pulpboard core materials due to exposure to high temperature and high humidity cycles

Conditioning	Core material[1]	Change in properties of core materials[2]: Modulus of rigidity	Weight	Thickness	Length (with grain)	Width (cross grain)[3]
		Percent[4]	Percent[4]	Percent[4]	Percent[4]	Percent[4]
		High temperature				
After 4 days' exposure at 175° F.	Balsa A:	....	- 7.87	-1.33	-0.19	-0.57
	B:	....	- 8.31	-1.32	- .22	- .61
	Pulpboard A:	....	- 3.68	-1.07	- .12	....
	B:	....	- 3.34	- .80	- .15	....
Reconditioned 4 days at 75° F., 65 percent relative humidity	Balsa A:	+ 1.2	- .24	.00	- .04	- .05
	B:	- 1.7	- .12	+ .26	- .03	- .08
	Pulpboard A:	+ 1.8	+ .04	- .27	.00	....
	B:	+ .9	+ .41	.00	- .05	....
After second exposure 4 days at 175° F.	Balsa A:	....	- 8.00	-1.06	- .21	- .55
	B:	....	- 8.50	-1.05	- .22	- .64
	Pulpboard A:	....	- 3.80	-1.33	- .12	....
	B:	....	- 3.41	-1.06	- .17	....
Reconditioned 4 days at 75° F., 65 percent relative humidity	Balsa A:	.0	- .27	.00	- .04	- .03
	B:	+ 3.4	- .18	+ .26	- .03	- .09
	Pulpboard A:	+ 1.9	.00	- .27	.00	....
	B:	- 2.1	+ .51	.00	- .06	....

(Sheet 1 of 2)

Table 11.--Percent of change in properties of balsa and pulpboard core materials due to exposure to high temperature and high humidity cycles (continued)

Conditioning	Core material[1]	Modulus of rigidity	Weight	Thickness	Length (with grain)	Width (cross grain)[3]
		Change in properties of core materials[2]				
		Percent[4]	Percent[4]	Percent[4]	Percent[4]	Percent[4]
		High humidity				
After first exposure, 6 days at 97 percent relative humidity, 80° F.	Balsa A:	-31.4	+13.27	+3.43	+0.09	+0.53
	B:	-31.1	+13.21	+3.15	+ .14	+ .48
	Pulpboard A:	-25.6	+ 5.94	+2.41	+ .11	....
	B:	-27.5	+ 6.25	+2.13	+ .07	....
Reconditioned 4 days at 65 percent relative humidity, 75° F.	Balsa A:	- 7.1	+ 2.56	+1.58	.00	+ .12
	B:	- 6.5	+ 2.03	+1.05	- .01	+ .06
	Pulpboard A:	- 9.5	+ 2.77	+1.07	+ .02	....
	B:	-13.4	+ 3.00	+ .80	- .02	....
After second exposure 5 days at 97 percent relative humidity, 80° F.	Balsa A:	-31.0	+19.03	+4.48	+ .10	+ .60
	B:	-34.4	+17.27	+3.41	+ .10	+ .51
	Pulpboard A:	-27.4	+ 6.72	+2.41	+ .10	....
	B:	-31.0	+ 7.22	+2.13	+ .02	....
Reconditioned 4 days at 65 percent relative humidity, 75° F.	Balsa A:	- 6.8	+ 2.34	+1.05	- .02	+ .11
	B:	- 7.1	+ 2.56	+1.31	- .02	+ .04
	Pulpboard[3] A:	- 5.4	+ 2.78	+ .80	- .02	+ .11
	B:	-11.7	+ 3.05	+ .53	- .10	....

[1] A = edges protected with one coat of white lead and two coats of aluminum varnish; B = edges unprotected.

[2] Initial values were obtained after cores were conditioned for 4 days at 65 percent relative humidity, 75° F.

[3] No grain direction apparent in pulpboards.

[4] Based on original values.

(concluded)

Table 12.--Average loss in weight of balsa and pulpboard core materials exposed to fungus attack[1]

Core material	Type of fungus: Poria incrassata	Poria microspora	Polyporus versicolor	Polyporus versicolor in soil	All exposures
	Percent	Percent	Percent	Percent	Percent
	One month's exposure[2]				
Aspen -- controls..........	7.4	18.7	16.9	39.7	20.7
Pulpboard -- no sealer.....	.0	.0	.0	.0	.0
Balsa -- no sealer.........	.0	.0	9.3	27.3	9.1
Pulpboard -- edges sealed.	.0	3.6	.0	.0	.9
Balsa -- edges sealed......	.0	.1	21.6	14.1	8.9
	Three month's exposure[3]				
Aspen -- controls..........	21.1	35.9	51.7	74.7	45.8
Pulpboard -- no sealer.....	2.5	12.9	.0	.2	3.9
Balsa -- no sealer.........	2.9	.6	46.7	48.5	24.7
Pulpboard -- edges sealed.	.0	25.8	.2	1.9	6.9
Balsa -- edges sealed......	5.5	10.5	51.3	33.8	25.3

[1]Based on equilibrium weight at 65 percent relative humidity.

[2]Average of 3 specimens.

[3]Average of 6 specimens.

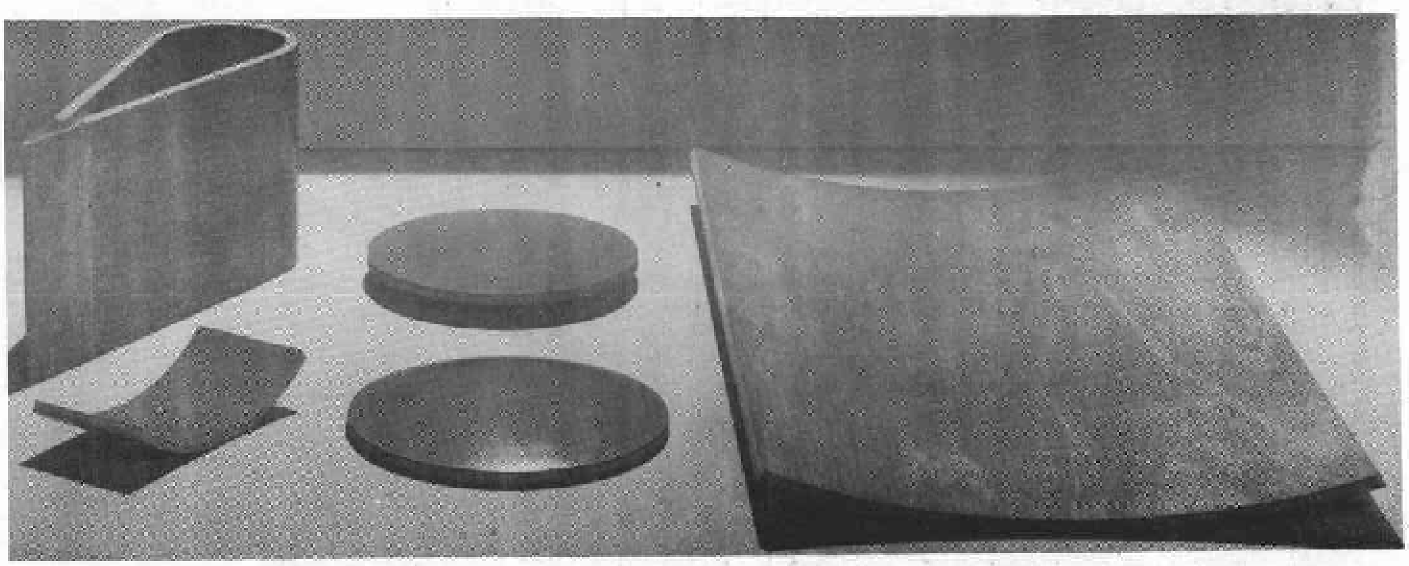

Figure 1.--Samples of sandwich construction with pulpboard cores in single and double curvature.

Z 62735 F

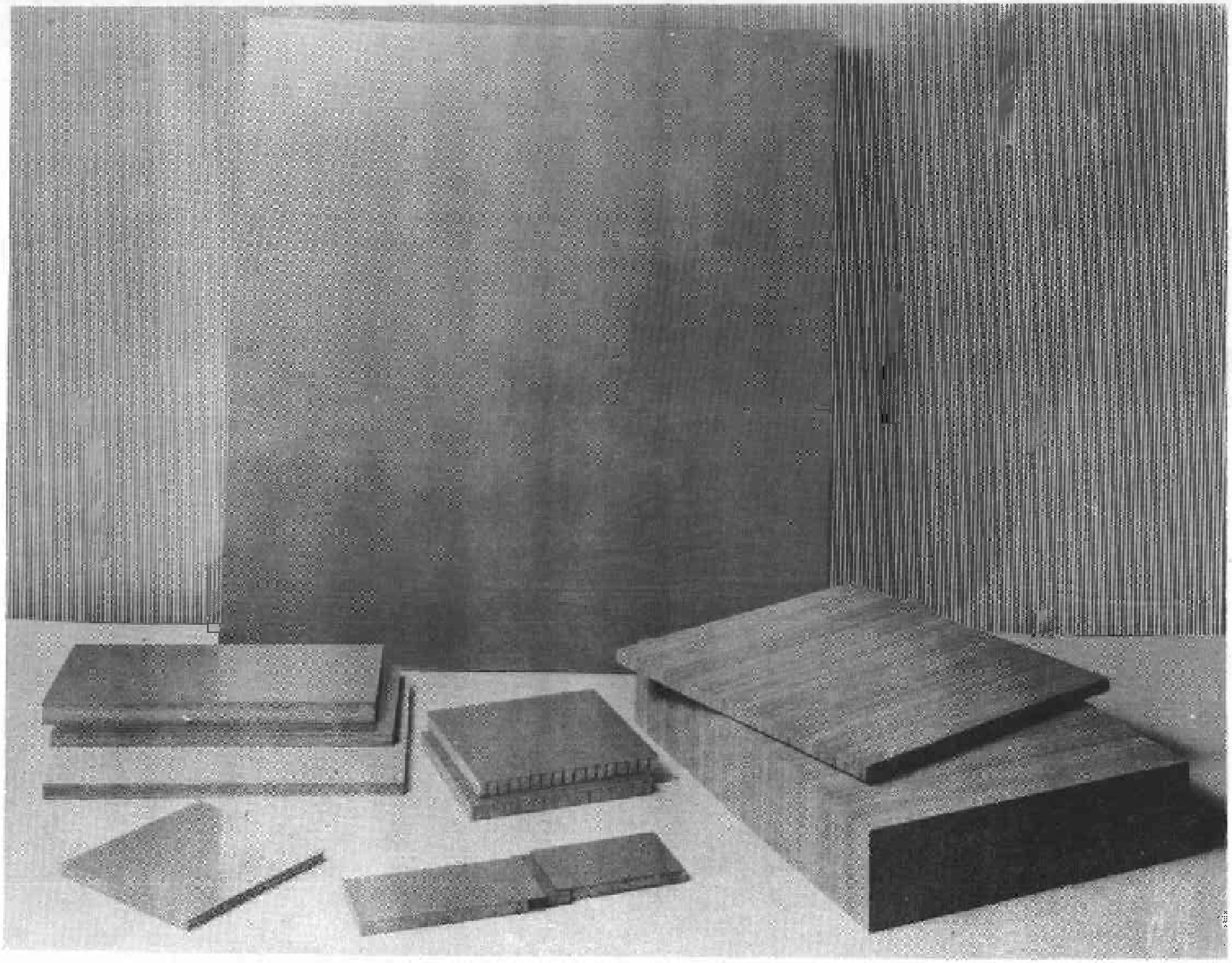

Figure 2.--Samples of sandwich constructions with pulpboard cores using the board flatwise and also as "face-to-face" laminations between the facing panels.

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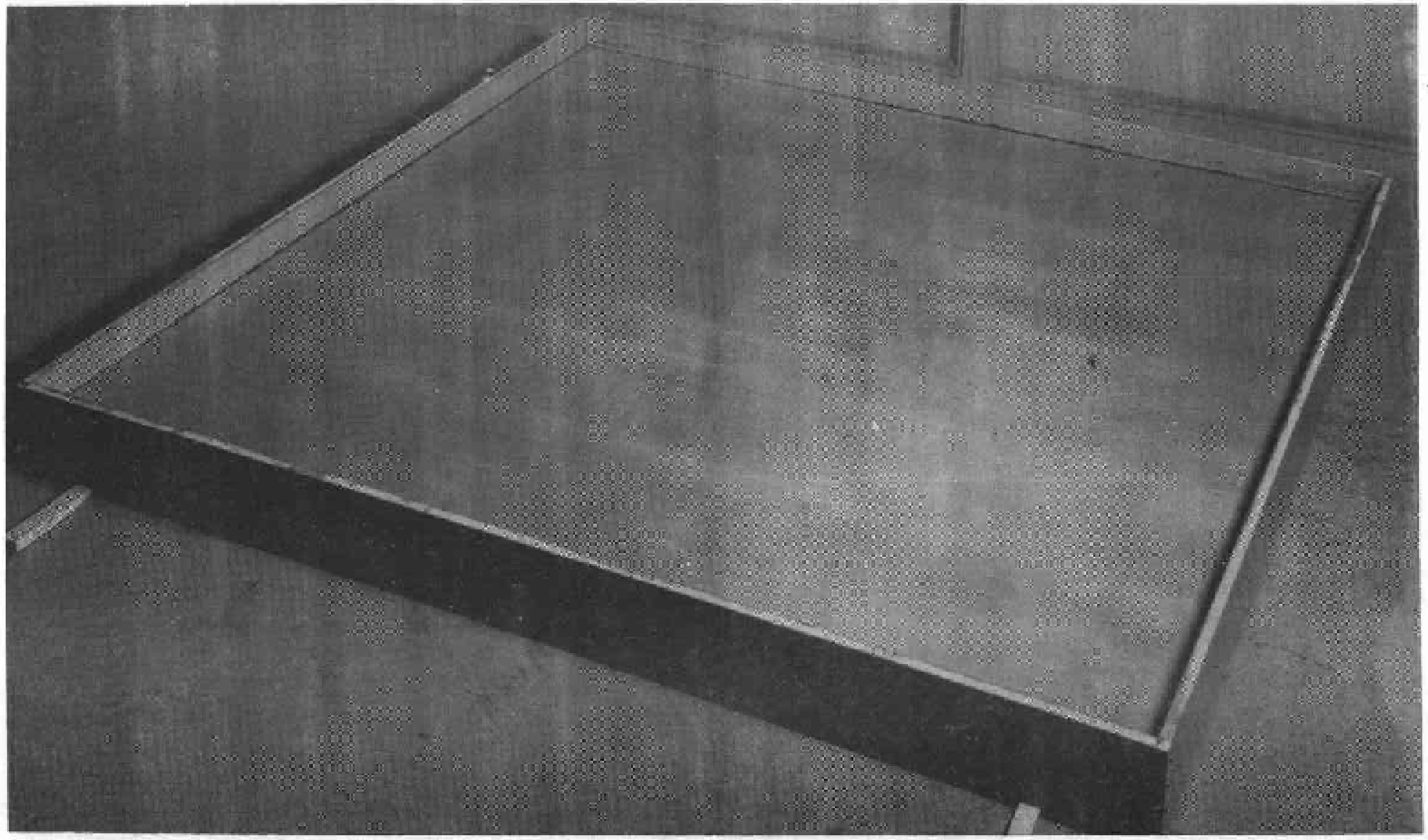

Figure 3.--Leveled tray for resin treating 4- by 4-foot pulpboards for core material.

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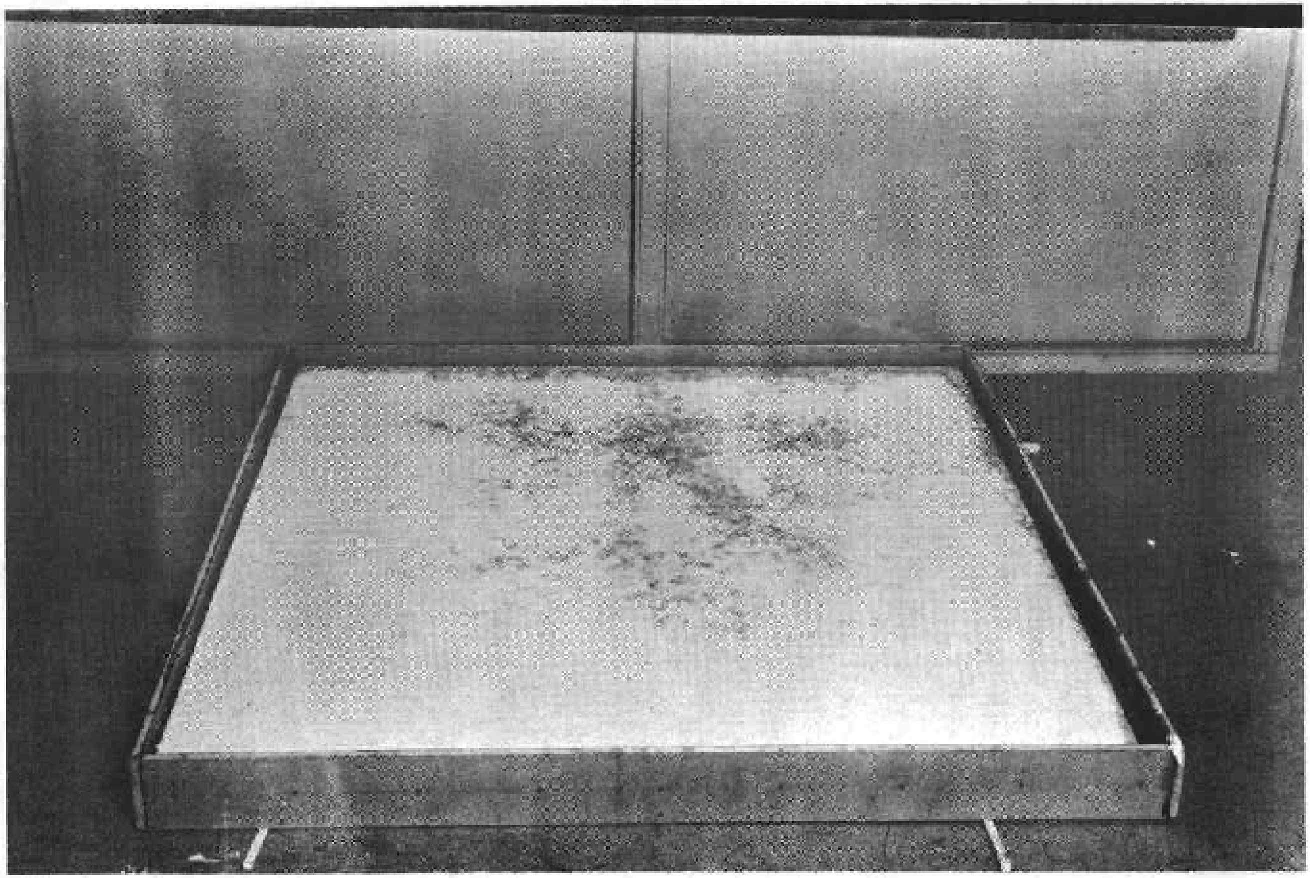

Figure 4.--Resin-treated pulpboard in tray, showing partial diffusion of resin through pulpboard after about 5 minutes. A cover was used over the tray to prevent evaporation of solvent during the period of diffusion.

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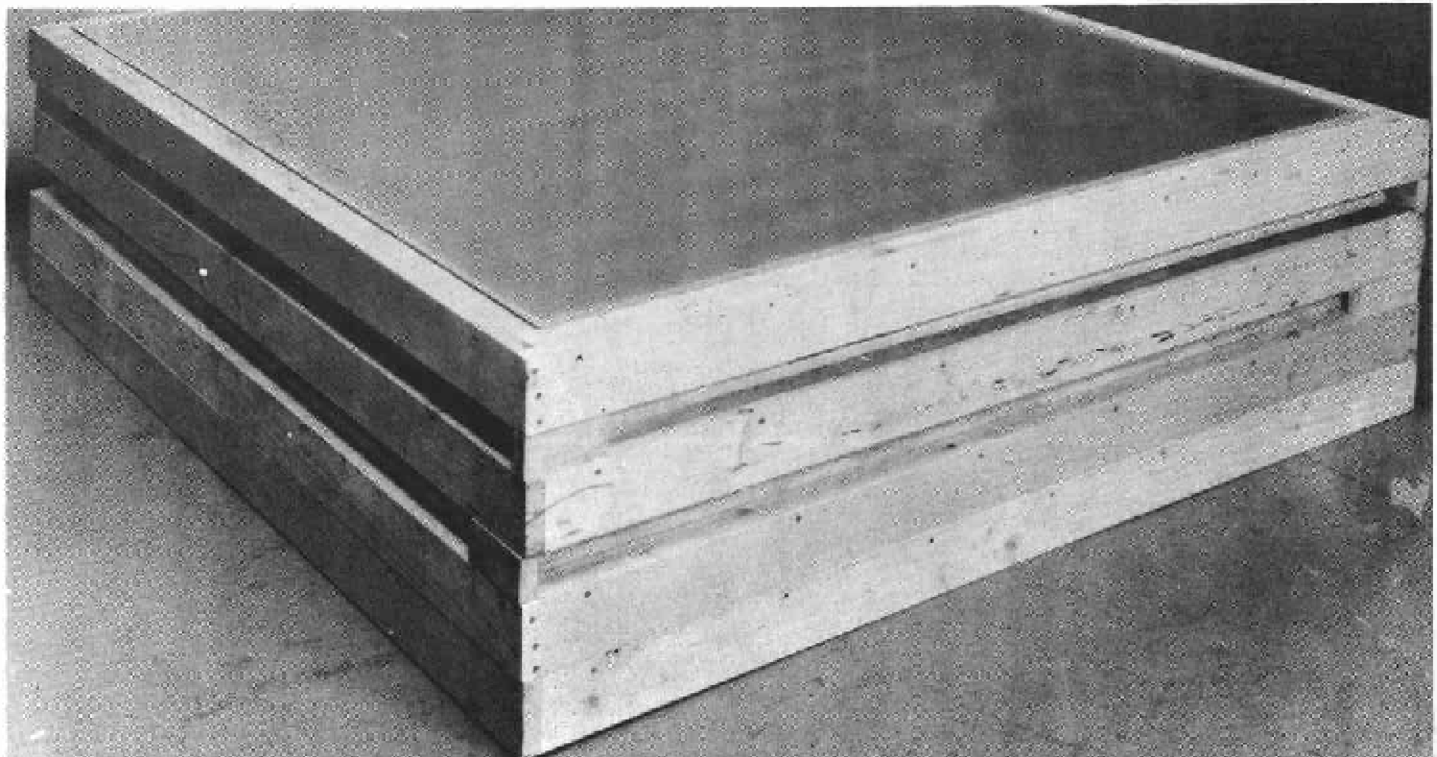

Figure 5.--Arrangement for slow air-drying of resin-treated pulpboard. One surface of the treated pulpboard is exposed to the air.

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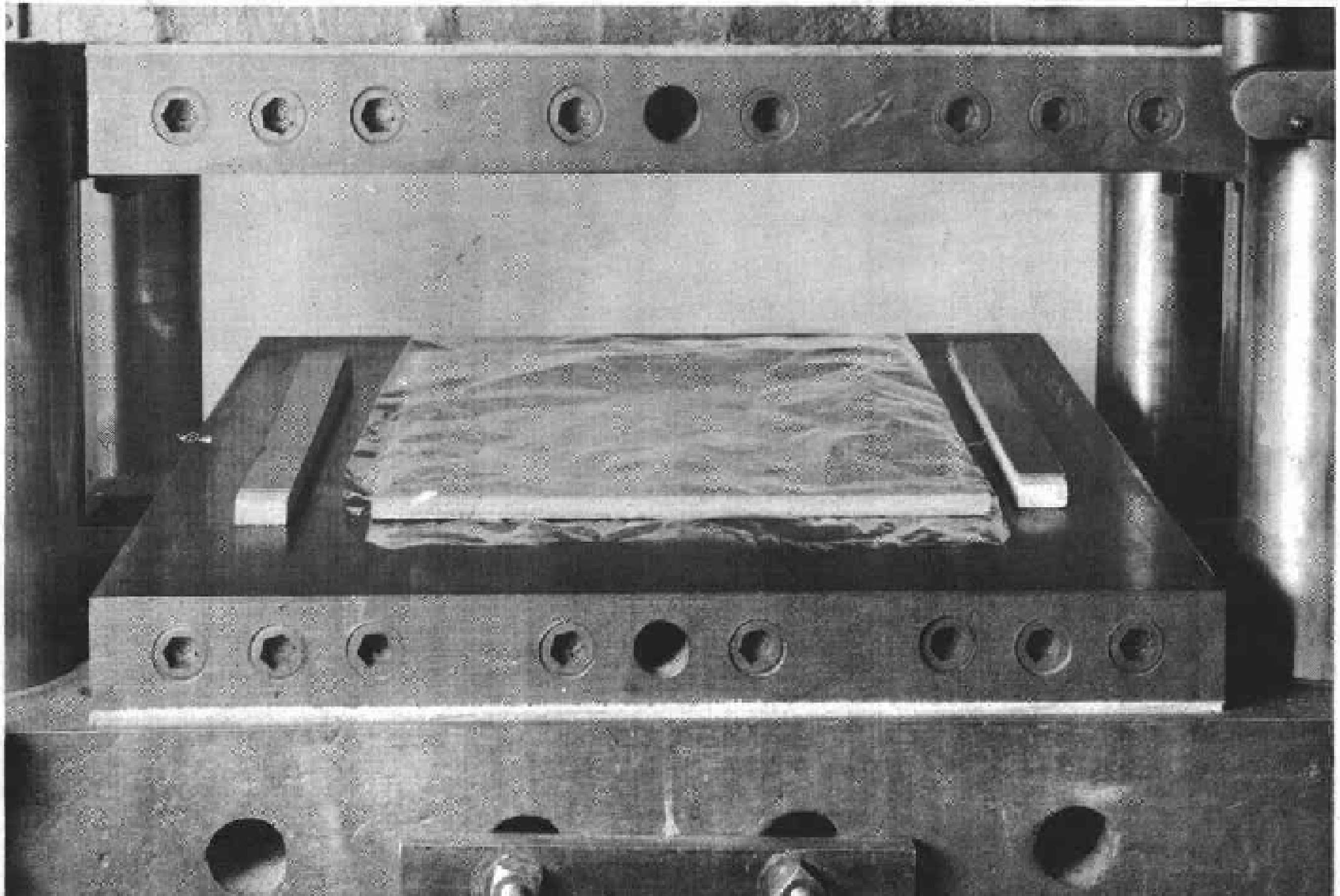

Figure 6.--Curing of resin-treated pulpboard in a hot press, showing "stops" to control final thickness. The dried pulpboard is wrapped in cellophane before placing in the press to prevent sticking to the press.

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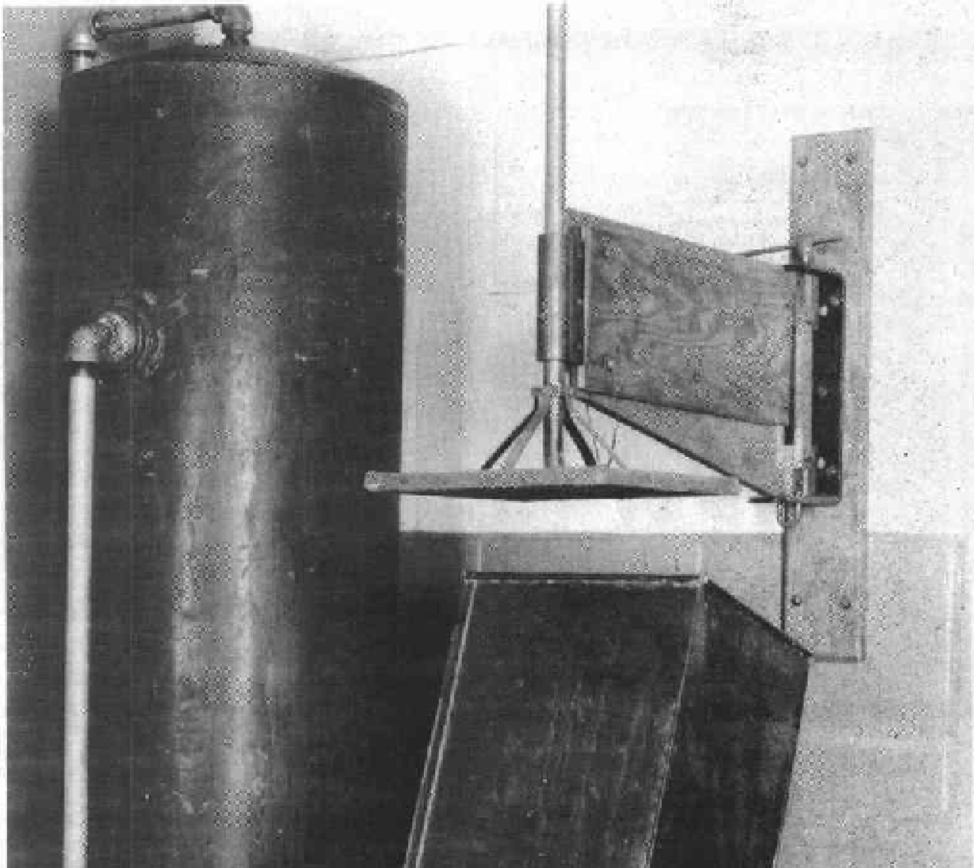

Figure 7.--Experimental pulpboard-forming apparatus.

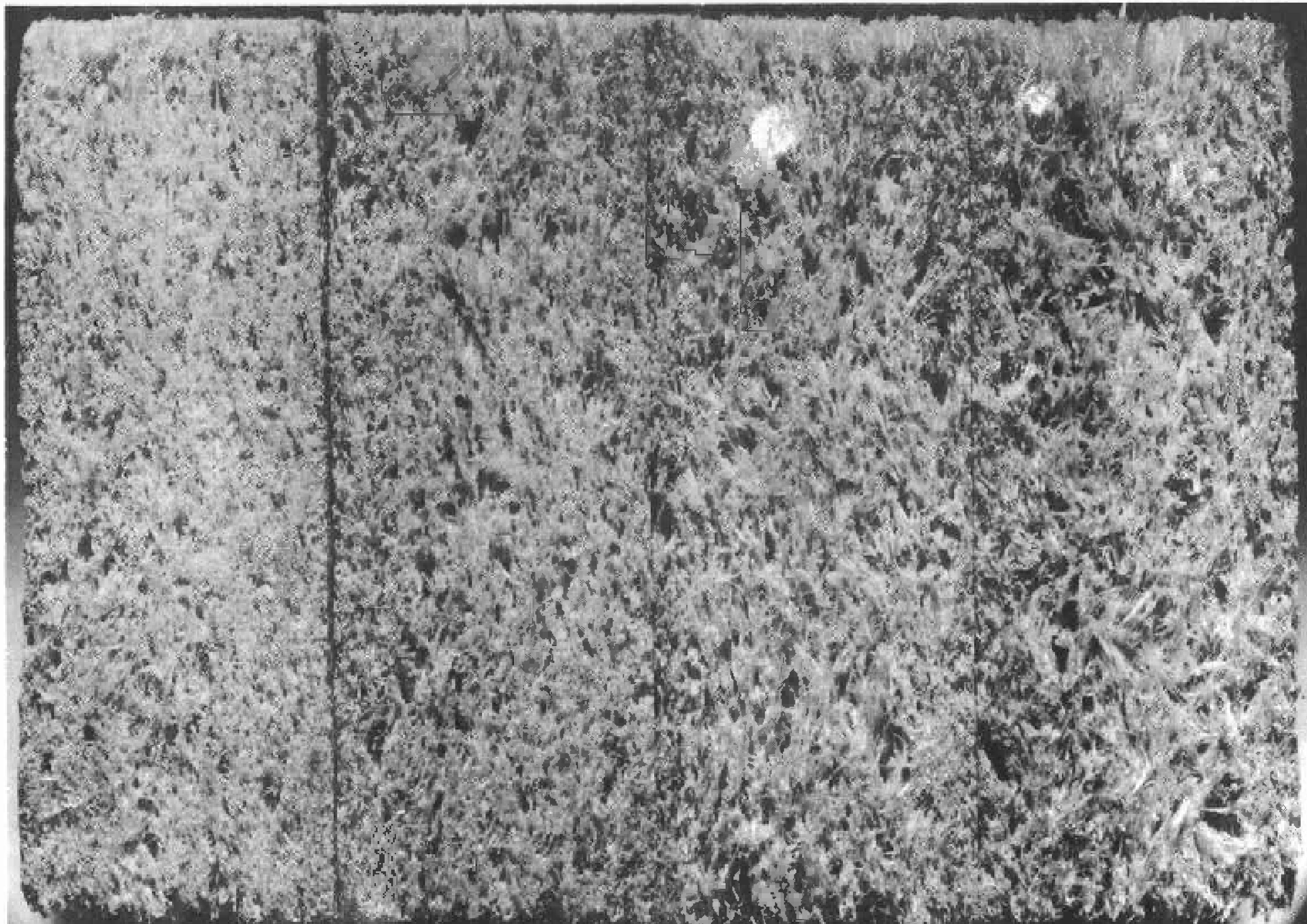

Figure 8.--Enlarged photograph of pulpboard core material showing orientation of fibers parallel to faces of formed panels.

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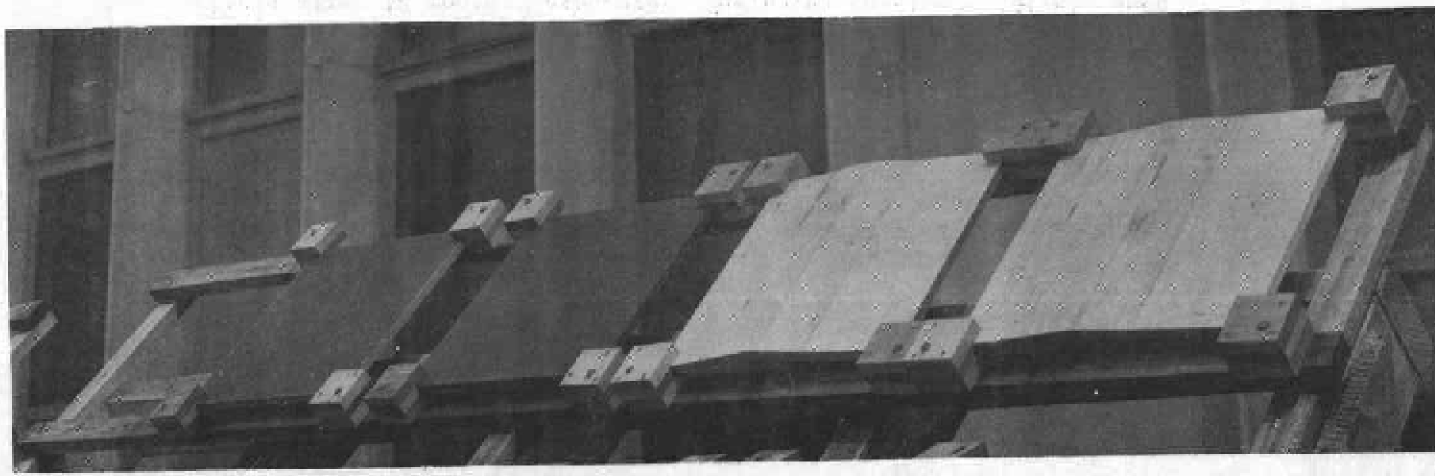

Figure 9.--Specimens of pulpboard and balsa wood core materials on exposure rack at Forest Products Laboratory for outdoor weathering tests after 3 months' exposure. The balsa specimens (right) show some warping, while the pulpboards show none.

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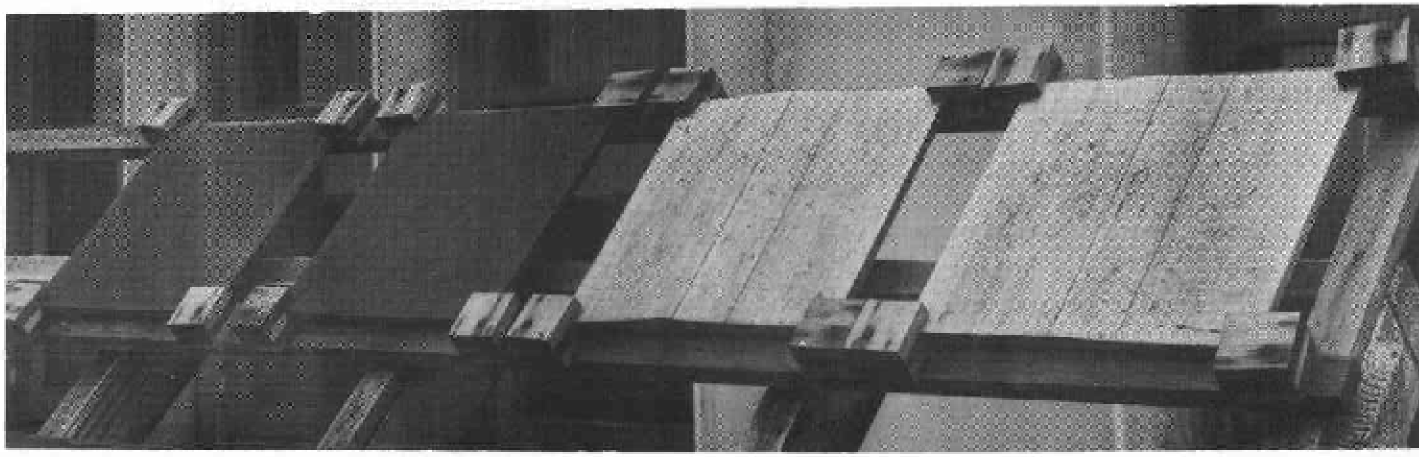

Figure 10.--Specimens of pulpboard and balsa wood core materials on exposure rack at Forest Products Laboratory for outdoor weathering tests after 12 months' exposure. The balsa specimens (right) show considerable warping and staining.

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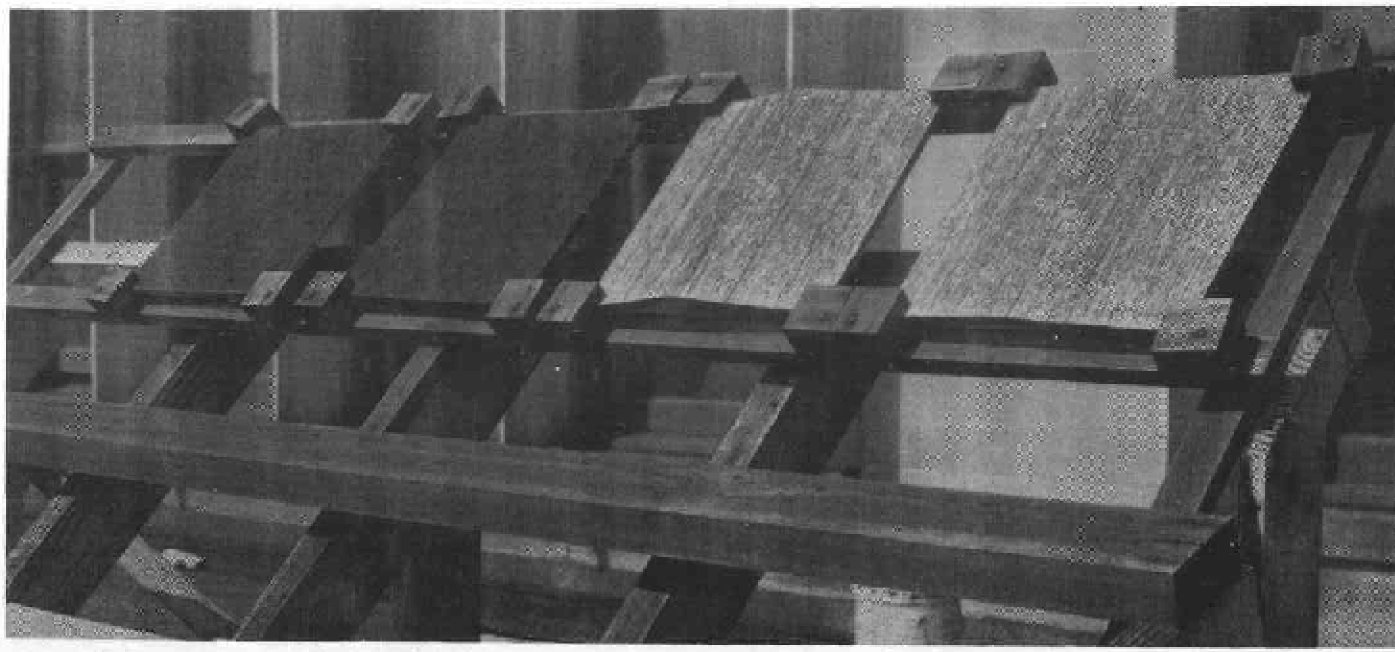

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Figure 11.--Specimens of pulpboard and balsa wood core materials on exposure rack at Forest Products Laboratory for outdoor weathering tests after 21 months' exposure. The pulpboard specimens (left) appeared sound and only slightly warped, while the balsa wood was sharply warped and badly weathered.