DURABILITY OF LOW-DENSITY CORE MATERIALS; AND SANDWICH PANELS OF THE AIRCRAFT TYPE AS DETERMINED BY LABORATORY TESTS AND EXPOSURE TO THE WEATHER

July 1949

This Report is One of a Series
Issued In Cooperation with the
AIR FORCE-NAVY-CIVIL SUBCOMMITTEE
on
AIRCRAFT DESIGN CRITERIA
Under the Supervision of the
AIRCRAFT COMMITTEE
of the
MUNITIONS BOARD

No. 1573-A

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
FOREST PRODUCTS LABORATORY
Madison 5, Wisconsin
In Cooperation with the University of Wisconsin

DURABILITY OF LOW-DENSITY CORE MATERIALS AND SANDWICH PANELS OF THE AIRCRAFT TYPE AS DETERMINED BY LABORATORY TESTS AND EXPOSURE TO THE WEATHER[1,2]

Part II

By

BRUCE G. HEEBINK, Engineer
WILLIAM J. KOMMERS, Engineer
and
ALVIN A. MOHAUPT, Technologist

Introduction

The purpose of these studies was to obtain information on the durability of sandwich construction of the aircraft type. The work was done at the Forest Products Laboratory under the joint direction of the Air Materiel Command, U. S. Air Force; Bureau of Aeronautics, Navy Department; and Civil Aeronautics Authority.

This report presents results of various tests on combinations of three core materials -- balsa, cellular cellulose acetate, and cellular hard rubber, and three types of facing materials -- aluminum, glass-cloth base plastic laminates employing several types of resins (hereafter referred to as glass-cloth resin or glass-cloth facings), and plywood, assembled by using several typical gluing methods and laminating resins. Additional core materiels, of the honeycomb type, are currently being tested.

---

[1] This progress report is one of a series prepared and distributed by the Forest Products Laboratory under U. S. Navy, Bureau of Aeronautics No. NBA-PO-NAer 00619, Amendment No. 2, and U. S. Air Force No. USAF-PO-(33-038) 48-41E. Results here reported are preliminary and may be revised as additional data become available.

[2] This report covers the second part of a continuing study, the first part of which was covered in Forest Products Laboratory Report No. 1573 of the same title.

Summary

Nine sandwich constructions (made with aluminum, glass cloth, and plywood facings on end-grain balsa, cellular cellulose acetate, and cellular hard rubber cores bonded with several typical adhesives and resins) were subjected to the following exposures: water immersion, high humidity, high temperature, alternate high-low temperature and humidity, and weathering. The relative durability of each construction was determined by tension and edge compression tests, wight and dimensional measurements, observation, and measurements of warp.

Considerable variation was evident in the test results. It is difficult; therefore, to present clearly the effect of the different exposure conditions; however, certain trends and apparent effects can be summarized.

Weight and dimensional changes in general duplicated those reported earlier for the same facings and cores in Forest Products Laboratory Report No. 1573. Unsealed balsa-glass cloth panels gained from 78 to 140 percent in weight, with various resins and facings during the water immersion; at the other extreme, edge-sealed acetate-aluminum panels gained only 3 to 13 percent. Transverse dimensional changes reflected the properties of the facings only and those for plywood were usually 2 to 3 times those for either glass cloth or aluminum. Changes in thickness followed the same trends exhibited by the respective core materials in tests described in Report No. 1573.

The strength of the glass cloth-balsa construction, regardless of the bonding resin used, was most adversely affected by water immersion. One aluminum-balsa construction and three glass cloth-acetate constructions also seemed to be considerably affected. The remaining combinations retained essentially their original strength.

The exposure to high temperature appeared to affect the strength of specimens having balsa cores to a greater degree than those having acetate cores. The percentage of core failure after heating was considerably higher than for the control specimens, indicating an effect of the exposure on the core material rather than on the adhesives and resins.

The exposure to high humidity materially reduced the tensile strength of six of the eight combinations having balsa cores. Only one of the combinations with acetate cores showed appreciable reduction in tensile strength. Tho edgewise compression strength of four balsa-core combinations and three acetate combinations was also considerably reduced.

The results of tension tests after cyclic exposure were inconsistent, and no definite conclusions can be drawn on the effect of this exposure.

Visual observation made after a year's exposure to the weather indicated a limited amount of edge shrinkage in the unprotected acetate and balsa cores. Proper protection of the edges appeared to eliminate this shrinkage, as the edge-protected specimens showed no evidence of shrinking.

Strength tests made after the weathering exposure showed that the glass cloth-balsa canbinations were most adversely affected, with a loss in strength of approximately 15 percent, while all panels having aluminum facings appeared to gain in edgewise compressive strength. There was no apparent difference, as judged by strength tests, between panels that were unprotected and those having sealed edges.

Measurements of warp after the weathering exposure indicated that the specimens having plywood facings were seriously cupped and twisted after only 3 months' exposure. The warping of aluminum-faced panels was a function of temperature only. Panels with glass cloth facings appeared to be the most stable. Panels having plywood facings were permanently warped by the weathering exposure, while those faced with aluminum and glass cloth were not.

Description and Preparation of Materials

Cores

Balsa.—The following specifications were used in obtaining balsa from a commercial source:

> Balsa lumber, surfaced two sides, weight 5-8 pounds per cubic foot, kiln dried, random widths (3 inches minimum), random lengths (6 feet minimum), thickness, 1-1/2 inches or 2-1/2 inches with not less than 50 percent of the matorial 2-1/2 inches in thickness, with ± 1/8 inch allowable tolerance.

The pieces as received were kiln dried, if necessary, and conditioned to a moisture content (5 to 7 percent) corresponding approximately to the relative humidity of the atmosphere in the workrooms.

The individual pieces were accurately jointed and planed to a rectangular cross section and later sawed into 1/2-inch end-grain slabs.

Cellular Hard Rubber.—Thismaterial is an expanded, hard, black, synthetic cellular rubber of the butadiene-acrylonitrile type, hereafter referred to in this report as cellular hard rubber or merely as rubber. As received from a commercial source it was in the form of slabs, approximately 1-1/2 by 20 by 36 inches, The density, after removing the outer hard skin and adjacent high-density material, varied between 6.2 and 7.2 pounds per cubic foot.

These slabs of cellular hard rubber were jointed to remove the tough outer skin and adjacent layer of high-density material and subsequently cut on a band saw and planed to a thickness of 1/2 inch.

Cellular Cellulose Acetate.-—The cellular cellulose acetate was manufactured commercially on a pilot-plant scale from cellulose acetate and approximately 3 percent of chopped glass fibers by an extrusion process employing heat and pressure.

The material was received in the form of extruded bars, white in color, approximately 5/8 by 5–5/8 inches in cross section, and from 4 to 10 feet in length. The outer surface of the bar was composed of a dense firm skin which was subsequently removed. After removal of this skin, the density ranged between 6.0 and 6.8 pounds per cubic foot,

The outer skin of one side and both edges was removed by jointing, after which the bars were reduced to 1/2–inch thickness with a wood–cutting band saw having five teeth per inch and running at 4,000 feet per minute.

Facings

Plywood.––Plywood facings conforming to U. S. Air Force Specification AN–NN–P–511b dated October 28, 1942 were 0.070 inch thick, three–ply birch, glued with a phenolic–type sheet glue.

Aluminum.—-Alminum facings were 24S–T3 0,020 inch thick conforming to Army–Navy Aeronautical Specification AN–A–13, January 14, 1943.

Glass Cloth–Resin.—Heat–treated glass cloth[3] No. 112-111, 0.003 inch thick and having a basket weave, was impregnated and wet–laminated to the cores with each-of five typical contact-pressure laminating resins to form glass cloth–resin facings. The following designations denote the characteristics of the five laminating resins used:

(a) A high-viscosity polyester type.
(b) Low–viscosity, polyester type.
(c) High–viscosity, polyester type.
(d) High–temperature–setting, low–viscosity polyester type.
(e) Low–viscosity, resin phenolic type.

Preparation of Panels

Two panels, approximately 1/2 inch thick and 36 inches square, were fabricated for each combination of core, facing, and resin. These panels were cut into individual test specimens for exposure as shown in figures 1 and 2. One panel, cut as shown in figure 1, was designated as panel type A and the specimens were used for weathering exposure tests, A similar panel, cut as shown in figure 2, was designated as panel type B, and the specimens were exposed to ell of the exposures listed above, other than weathering.

[3] In general, only two finishes for glass cloth have been in production use for structural parts, the No. 112-111 used in the tests here reported, which is heat treated, and the present No. 114, which is heat–cleaned and water repellent sized, It is well known, from a large number of tests by many sources, that the No. 114 is very considerably more water and humidity resistant from the point of view of drop-off of strength properties than the No. 112-111.

Plywood to Balsa

Panels having plywood facings and end-grain balsa cores were glued with a high-temperature-setting melamine resin, adhesive R[4] [5]. The adhesive was spread on the plywood by brush to a weight of 24 grams of wet glue per square foot. After an open-assembly period of 1 day, the panels were assembled and bag molded on a flat, aluminum mold. The curing cycle was 15 minutes at 50 pounds per square inch and 300° F.

Aluminum to Balsa

Method 1.--A high-temperature-setting liquid resin and a thermoplastic powder, adhesive G, were applied to the etched aluminum facings. The thermosetting liquid was brushed to a wet spread of about 20 grams per square foot, While the liquid was still wet, the thermoplastic powder was sifted on the surface and, after drying, the excess was removed. After a 24-hour open-assembly period these facings were pressed to the balsa cores in a bag at 275° F. and a pressure of 75 pounds per square inch for 1 hour.

Method 2.--A high-temperature-setting modified thermoplastic resin, adhesive F, was brush spread on the etched aluminum surface. The adhesive was thinned with a mixture of ethyl acetate and ethyl alcohol and applied at the rate of 12 grams of dry glue per square foot. About four coats were required with a half-hour drying period after each. The final coat was air dried for 24 hours before the panels were pressed. Pressing was done as described in method 1 above.

Method 3.--This method incorporated the use of adhesive M, a high-temperature-setting, modified thermosetting, priming resin applied in six spray coats directly to the etched aluminum. After air drying overnight, the rosin was cured in an oven at 325° F. for 30 minutes. The surfaces were sanded and bonded to the balsa core with a high-temperature-setting phenolic resin, adhesive H, in a bag at 230° F. and a pressure of 75 pounds per square inch for 1 hour.

Glass Cloth to Balsa and Glass Cloth to Cellulose Acetate-

Panels having resin-impregnated glass cloth facings and balsa cores were assembled and cured in one operation with no additional resin between the facings and the core. The normal procedure was to cover a blanket-covered plywood caul with a sheet of 0.020-inch aluminum and a parting film of cellophane. The impregnated glass cloth for one facing was then laid one sheet at a time, cross-laminated, on the cellophane-covered surface. This procedure was repeated for the other facing. The balsa core was then laid on one of the facings and covered with the layup for the opposite side.

---

[4]Notations used for the various adhesives are the same as given in Forest Products Laboratory Report No. 1574, "Fabrication of Lightweight Sandwich Panels of the Aircraft Type."

[5]Description of all resins and adhesives used is given in Appendix I.

This combination of panel and cushion cauls was inserted in a hot press and cured at a pressure of about 13 pounds per square inch and a suitable temperature and time depending on the type of resin.

Method 1.--Laminating resin A was applied to the glass cloth in an adaptor for a glue spreader, as shown in figure 3. This resin has a nonvolatile content of approximately 98 percent, and was therefore applied to the glass cloth at the rate of approximately 45 percent of the total coated weight. The panels were molded, using a temperature of 225° F. for 1-1/2 hours.

Method 2.--Laminating resin B was coated on the glass cloth to a wet resin content of about 50 percent. This resin has a nonvolatile content of approximately 70 percent, which made it necessary to use the coated glass cloth within 2 or 3 hours after spreading.

The panels were molded at a temperature of 250° F. for 1-1/2 hours.

Method 3.--Laminating resin C, very similar to resin A, was used in this method and cured at a temperature of 240° F. for 1-1/2 hours.

Method 4.--This resin was a high-temperature-setting, low-viscosity polyester type, resin D, and the application was identical to Method 2. Cure was accomplished at 250° F. in 1 1/2 hours.

Method 5.--Laminating resin E, wag applied only to the glass cloth-balsa combination. The glass cloth was impregnated by hand because the viscosity was too low for proper application on tho glue spreader adaptor. These panels were cured at 275° F. for 4 hours.

Plywood to Cellulose Acetate and Plywood to Cellular Hard Rubber

Panels having plywood facings bonded to cellulose acetate or rubber cores were fabricated by brushing a room-temperature-setting resorcinol resin, adhesive P, on the plywood facings only and pressing the panels at room temperature in a press for 5 hours at a pressure of 13 pounds per square inch.

Aluminum to Cellulose Acetate

The following three methods were employed in fabricating panels of this type.

Method 1.--The etched aluminum facings were sprayed with a high-temperature-setting, modified thermosetting resin, adhesive H, Four coats were applied with approximately 30 minutes of air drying after each coat. The final coat was air dried overnight and then cured for 30 to 45 minutes at 325° F. Light sanding with fine emery cloth prepared the surface for secondary gluing with adhesive P. A spread of 35 grams per square foot of secondary glue was brushed on the primed aluminum facings and then the panels were pressed in a bag at room tomperature for 7 hours at about 13 pounds per square inch pressure.

Methods 2 and 3.--These methods were the same as methods 2 and 3 used with the aluminum-to-balsa panels except that the pressure was reduced to 35 pounds per square inch.

Aluminum to Cellular Hard Rubber

These panels were made by the same procedure used with method 1 for the aluminum-to-cellulose acetate panels.

Glass Cloth to Cellular Hard Rubber

Only one resin was employed jn this combination because of the maximum temperature limitation of the core (about 225° F.) and the effect of the rubber core on proper resin cure. This process of fabrication employed resin A and was identical to method I used for glass cloth to balsa, except that extra catalyst (benzoyl peroxide) was applied directly to the core to assure proper cure of the resin.

Preparation of Test Specimens

Four types of specimens were prepared for this study; a panel about 5-1/2 by 6 inches, used to determine weight and dimensional changes; a tension specimen shown in figure 4; a weathering panel approximately 16 by 25 inches; and a short column edgewise Compression specimen about 2 by 3 inches.

Four of the 5-1/2- by 6-inch panels were prepared for each exposure, two with unprotected edges and two with well-painted edges. The edge coat-ing consisted of one coat of lead primer (1,000 parts by weight of white lead paste, 97 parts ram oil, and 9.4 parts drier), which was allowed to dry for 24 hours at room temperature, followed by two separate coats of aluminized varnish (1-1/2 pounds of aluminum paste, fine aircraft-use grade, to 1 gallon of phenolic resin varnish conforming to Specification AN-TT-V-116) with an 8-hour drying interval between coats.

Eight to 10 tension specimens were prepared for each exposure condition, including the weathering exposure.

Two panels of each combination, approximately 16 by 25 inches, were cut as shown in figure 1 for determining the effect of weathering on distor-tion, such as cupping and twisting. One was exposed with unprotected edges, while the other had the edges sealed as described above for the 5-1/2- by 6-inch panels. Provisions were made for tension tests after exposure by applying (and curing) a metal priming cement, adhesive M, to a strip about 1-1/2 inches wide across the center of each aluminum facing before the panels were assembled.

Specimens for the determination of the compressive strength of the sandwich materials in the direction parallel to the plane of the sheets were cut from the large weathering panels, as shown in figure 1, The specimens were nominally 2 inches wide and 3 inches long. The control compression specimens were cut and tested prior to exposure, while the final compression specimens were cut and tested following exposure of the panel. The 5-1/2 by 6-inch specimens were also cut into four nominal 2- by 3-inch edgewise compression specimens after weight and dimensional data had been obtained following exposure.

Treatment of Specimens

All indoor exposure specimens were first conditioned to approximate weight equilibrium at 75° F, and 65 percent relative humidity and then divided into groups for the following exposures[6].

(a) Immersion in running tap water, approximately 55° F., for 24 hours.

(b) Immersion in running tap water for 40 days.

(c) Immersion in running tap water for 40 days followed by reconditioning to approximate weight equilibrium at 75° F, and 65 percent relative humidity.

(d) Placed in a room maintained at a temperature of 80° F. and 97 percent relative humidity until approximate weight equilibrium has been reached.

(e) Brought to equilibrium at 80° F. and 97 percent relative humidity, followed by reconditioning to 75° F. and 65 percent relative humidity.

(f) Placed in an insulated box for 240 hours maintained at 200° F. dry heat, tested hot.

(g) Maintained at 200° F. for 240 hours, followed by reconditioning to 75° F. and 65 percent relative humidity.

(h) Cyclic exposure, one cycle consisting of the following:

(1) 24 hours at 175° F. and 75 percent relative humidity
(2) 24 hours at -20° F.
(3) 24 hours at 175° F. dry heat
(4) 24 hours at -20° F.

The small weathering specimens were inspected for glue-joint integrity, completeness of edge coating, and general appearance. They were then brought to approximate equilibrium with 75° F. and 65 percent relative humidity and carefully weighed and measured prior to exposure. The specimens were placed on racks by attachment at the points, with a brass spring beneath each point and a screw hook above, as shown in figure 5. This arrangement allowed free movement and easy removal of specimens,

The large weathering panels were conditioned and inspected in a similar manner and, in addition, were measured for flatness. This was done by means

---

Products Laboratory Report No. 1573.

of a straight edge having a dial indicator calibrated in 0.001-inch increments mounted in the center. Six readings were taken on the concave side, one near each edge and two from diagonal corners. This measuring device is shown in figure 6. The panels were then mounted by 3-point support, similar to the small panels, as shown in figure 5.

On July 1, 1946, the exposure was started by facing the panels south at an angle of 45° to the horizontal. The specimens mere inspected, weighed, and measured at the end of 3, 6, 9, and 12 months' exposure.

Description of Test Procedures

In general, the test methods conformed to those described in Forest Products Laboratory Report No. 1556, "Methods for Conducting Mechanical Tests of Sandwich Constructions at Normal Temperatures," revised March 1948.

All tests, except those which required a temperature of 200° F., were conducted in a room in which the temperature was controlled at 75° F. and relative humidity at 65 percent. Dimensions and weights of all specimens were taken immediately before test. Normal testing techniques or practices mere supplemented with the following variations:

(4) Specimens that were immersed for 1 and 40 days were blotted to remove suface or free water, weighed, measured, and tested immediately.

(B) The specimens exposed to high relative humidity (97 percent) and not reconditioned were kept in a closed container (a few at a time) to prevent a change in their moisture content during the interval of time required for weighing, measuring, and awaiting test, Equipment was not available for testing the specimens exposed to high relative humidity,

(C) A small insulated plywood box housing the specimen and necessary apparatus was used to conduct the tests at 200° F, The box, shown in figure 7, was equipped with double glazed door end windows, heating coils, thermostat, and a fan for circulating the air within the box.

The large weathering panels were measured for warp immediately after removal from the test racks on the Laboratory roof. During the winter months any snow or ice on a panel was removed by a hand scraper. These measurements were taken on the concave side of each panel with the straight edge and dial gage. The straight edge was placed on the panel in six different positions, and the measurement from the straight edge to the face of the panel, at the center of each span, was recorded. Each panel was identified by a number painted on one side of the panel; this side was always placed down or away from the sun and weather. Measurements with the numbered face in the concave position were given a positive value, those with the opposite face in the concave position were given a negative value. The amount of cupping was determined from the average change in deformation along the edges of the four sides of each panel, The amount of twist was determined from the average change in deformation across the two diagonals of each panel.

Weights and measurements of thickness, width, and length were obtained from the large and the mall weathering panels after they had been brought inside the building.

Initial and final tension specimens were obtained from strips cut from both type A and B panels. Initial and final edgewise compression specimens were obtained from each panel type A, but only final, specimens were obtainable from each of the type B panels. Therefore initial, or control, tensile strength values were obtainable for both panel types, but the control edgewise compressive strength as determined for each of the type A panels was used as the initial strength of both panels,

The specimens were selected for each individual indoor exposure by a sampling method, representing as many different portions of each panel as possible. This was done to determine the average properties of each panel, and to reduce the effect of a possible variation in strength or dimension within any one panel,

Presentation of Data

Table 1 is a compilation of all the tension test data obtained from the tests of specimens cut from the B panel of each construction. The table includes data from control and all controlled exposure tests, but does not include weathering–test data. Figures listed in the table under "controls" are the averages obtained from nine individual tests; all other figures are the average obtained from six tests.

Table 2 presents the data obtained from edgewise conpression tests of specimens subjected to the controlled exposures. The average "control" strength, as given for each construction, was determined from tests of seven specimens cut from each "A" panel. The high and low strength values (pounds per inch of width of specimen) are also listed for each panel. The specimens subjected to the various exposures were cut from the "B" panels and the percentages of "control" strength based on 12 specimens for each exposure are presented.

Table 3 presents a summary of the weather conditions for Madison, Wis., for the period during which the weathering specimens were exposed. Monthly averages of temperatures and relative humidities are included, along with total precipitation and amount of sunshine. Data on normal mean temperature and normal precipitation are also included for comparison of conditions during this period to normal conditions as judged by past records.

Table 4 presents a summary of the edgewise compressive strength data from tests of the outdoor weathering specimens, for both large and small panels cut from the "A" panels. The control strength values are the same as shown in table 3. The average strength values were computed from the results obtained from eight tests for the large panels, and from 16 tests for the small panels. In addition, the table includes the average strength of the specinens having sealed edges and those having unprotected edges after the 12 months' weathering exposure.

Table 5 is a summary of the tension test data obtained from the tests of specimens cut from the A panel of each construction, Only the "control" strength and the strength following 12 months of outdoor weathering are presented for each construction; however, the high and low values and the average tensile strength of those specimens cut from weathering panels having painted and unpainted edges have been included, Ten specimens were tested to determine the average control strength, and 10 specimens were cut and tested from both the painted and unpainted panels following the weathering exposure.

Table 6 presents a summary of the effect of weathering on weight, dimensions, and flatness of the sandwich constructions under study, All measurments were taken on two panels for each construction approximately 1/2 by 16 by 25 inches in size, one with painted and one with unpainted edges. Dimensional changes are shown in thickness, average of width and length, cupping, and warping.

Results and Discussion

Effect on Weight and Dimensions

Weight and dimensional changes recorded for nominal 1/2 by 5-1/2 by 6–inch specimens during this study in general duplicated those reported earlier for the same facings and cares in Report No. 1573 and only a summary of the results will therefore be presented below.

In water immersion, the weight gain of each sandwich construction was controlled partly by the characteristics of the core and face material and partly by the quality of the edge seal. Unsealed balsa–glass cloth panels gained from 78 to 140 percent, with various resins in the facings, in 40 days' immersion, whereas edge–coated acetate–aluminum panels gained 3 to 13 percent, The glass cloth facings were poorer vapor barriers than the 1/16–inch birch plywood faces but absorbed less moisture,

The specimens with aluminum facings and painted edges absorbed much less moisture while immersed and retained more moisture during the reconditioning period. Edge painting did not appear to affect the dimensional change of the specimens, Inasmuch as the glass cloth facing material of the specimens tested is somewhat porous, the edge painting of these sandwich constructions was not so effective in excluding water as the edge painting of specimens having aluminum facings, However, other fabricating techniques may be used to produce glass cloth facings of lower porosity which may reduce the water absorption of the sandwich, It would seem advisable, from the results of these tests, to seal the edges of any sandwich construction fabricated with nonporous facings. The rate of change in weight of a sandwich structure thus protected will be materially reduced when exposed to changing moisture conditions.

Water Immersion

The glass cloth–balsa construction, regardless of bonding rosin (B, C, D, or E) was most adversely affected by the water immersion exposure (tables 1 and 2). This construction lost the most in tensile strength, approximately 55 percent, and edgewise compressive strength, about 70 percent, after 40 days' immersion. The aluminum-balsa construction bonded with adhesive F last about 50 percent of its tensile strength in this exposure. The glass cloth–acetate construction bonded with resins B, C, and D also seemed to be affected to the extent of a 50 percent loss in compressive strength and a 20 to 30 percent reduction in tensile values. The remaining combinations seemed to be relatively unaffected by the 40-day immersion except the plywood balsa in compression (approximately 50 percent loss).

When the specimens were reconditioned to 65 percent relative humidity and 75° F. tho strength of all of the constructions increased to tensile and compressive strength values reasonably close to their control values.

High–temperature Exposure

The high–temperature exposure for this series of tests consisted of heating the specimens to 200° F. and maintaining this temperature for 240 hours. The tensile strength of the specimens having cellular cellulose acetate core material appeared generally to be less affected by the heat than the balsa core specimens. As can be seen in table 1, there was considerable variation between the strength values for any one core material, which may be due in part to the glue bond between the core and the facing materials, or to variation in the density and homogeneity of the cores. The percentage of core failure for the specimens after heating, however, was generally higher than for the control specimens. Following reconditioning of the specimens, their tensile strength was approximately equal to or greater than the control strength with the exception of that of one alumhum-balsa construction (adhesive M + N). A possible explanation for this rather general gain may again be due to the additional curing of the glues during the heating, or may point to possible low values for the control tests, The specimens for the tension tests were chosen in a systematic manner from the panels, representing different areas of the "B" panels shown in figure 2. In every case the percentage of failure in balsa cores after exposure and reconditioning was higher than the control, indicating a weakening of the balsa during the exposure to 200° F.

The edgewise compressive strength of three of the constructions was often adversely affected by the heating exposure, but again there was a large range in values which mere used to determine the average strength for each construction. Upon reconditioning of the specimens following the heating, two of the above constructions did not return to within 20 percent of their original strength and appeared to have been permanently weakened by the exposure.

High-humidity Exposure

The specimens in this group were placed in a room in which a temperature of 80° F. and a relative humidity of 97 percent were automatically maintained, and remained in this atmosphere until approximate weight equilibrium had been reached. The tensile strength of the specimens having balsa cores was materially reduced for six of the eight combinations; those being bonded with adhesive G and M + N being relatively unaffected. The loss in strength of the other six in the wet condition ranged from 40 to 65 percent. Of these six combinations, two returned to normal strength upon reconditioning, but the other four were permanently reduced in strength, only one of the acetate core combinations showed significant reduction in tensile strength, Following reconditioning, all acetate core specimens had higher tensile strengths than the controls, This apparent gain in tensile strength of the materials was not the result of the exposure, but was again attributed to relatively low values obtained from the control tests.

The edgewise compressive strength of four of the balsa core combinations and three of the acetate core conbinations was reduced by approximately 50 percent or more, one glass cloth-balsa construction (bonded with resin D) being reduced approximately 80 percent. Upon reconditioning, four of the constructions with balsa cores and two with an acetate core did not return to within 90 percent of the control strength.

Cyclic Exposures

The specinens in this group were subjected to 1, 5, or 10 cycles of alternate high and low temperatures combined with high and low relative humidities. The results of the tension tests were inconsistent, and very little can be concluded as to the effect of the exposure on the tensile strength of the various sandwich constructions. It would bo expected that, if there were any detrimental effect, it would be aggravated by additional exposure cycles. Them may be a slight trend in tho reduction of tensile strength, with additional reduction following reconditioning to 65 percent relative humidity and 75° F. This latter effect may be due in part to the fact that the balsa core specimens were tested at a low moisture content following the high-temperature, dry portion of the cycle. When those specimens mere then reconditioned, their moisture content increased.

The edgewise compression tests were performed on specimens cut from the panels used for determinations of weight and dimensional stability, and thus values were obtainable after only the 10 cycles of exposure and after reconditioning, The results of these tests indicate that, when they were tested immediately following the exposure, there was only a slight reduction in the compressive strength for four of the 13 constructions, but that after reconditioning nine of the materials had slightly reduced strength values.

Weathering Exposure

The A type panels were exposed to the weather for 12 months, being removed from the racks at the end of each 3-month interval for observation. A summary of the weather conditions during this period is presented in table 3.

Visual observations.—-Upon inspection, certain changes were readily visible. All the panels faced with glass cloth were bleached by the action of the sun. The cellulose acetate cores showed considerable shrinkage in thickness at the edges, and in some cases the facings were pulled partially together at the corners. Balsa had also shrunk, but not to the extent of cellulose acetate. Edge shrinkage was visible in cellulose acetate after 2 months' exposure, but balsa showed no visible indications until the 3-month period. Cellular hard rubber was the most stable core, showing practically no edge shrinkage after 1 year's exposure to the weather. Coating the edges of the specimens reduced the edge shrinkage of the core to such a degree that it was not noticeable in any of the combinations.

Warp was most predominant in panels with cellular rubber cores. Cellular rubber panels with plywood facings warped the most and other combinations with aluminum and glass cloth facings warped more than corresponding panels with cellulose acetate and balsa cores.

The effect of weathering on the strength of the glue bond cannot be determined entirely form visual exmination. In most cases no delamination occurred along the edges and at the corners of the panels.

Strength tests.—The edgewise compression and tension specimens were cut fro6 these panels following the full 12-month exposure, with edgewise compression specimens cut only from the "A" panels.

Table 4 presents the results of tests on edgewise compression specimens cut from panels after exposure for 1 year to the weather, as compared to control specimens. A duplicate matching set of control specimens was tested after about 32 months' storage at control conditions (75° F. and 65 percent relative humidity). These results are also included in table 4. It will be noted that in general. these stored controls were equal to or weaker than the original controls. The two aluminum-faced panels bonded with H + P were reduced to about 70 percent of the original control values by the aging period.

The edgewise compressive strengths of 11 of the 20 sandwich constructions were reduced by the weathering exposure, as shown by the average strength values obtained from the tests of specimens cut from the large and small panels, conpared to average control values. The constructions most adversely affected by the exposure were the glass cloth-balsa combinations, with an average loss in strength of approximately 15 percent for 4 of the 5 combinations from both sizes of the original panels. Nine of the 20 combinations, however, presented strength values equal to or exceeding their controls. One of these, aluminum on balsa bonded with adhesive F, after weathering was almost double the control value.

The effect of the edge painting on the compressive strength was somewhat obscured by the wide variation in individual specimen strengths. For all the panels considered as one group, however, there was no apparent difference in strength between the specimens cut from the panels having the painted or from those having unpainted edges.

Considering the last column in table 4, which presents a comparison of all weathered specimens of each combination to the average of the original and stored controls, the following generalizations can be made:

1. All panels having aluminum facings developed equal or higher strengths after weathering than the controls.
2, All panels having glass cloth facings, except one, decreased in strength during weathering.
3. Both combinations having plywood facings decreased in strength with weathering.
4. Both panels bonded with resin D, although low in original strength as compared to similar panels, increased in strength with weathering.

The tensile strength, as shown in table 5, of the specimens cut from the weathered panels was lower than their controlstrengths for 10 of the 17 sandwich combinations tested. In table 5, no control strengths are given for two constructions: the specimens in these groups were not sufficiently strong to prevent breakage when they were cut from the panels by means of a circular saw. This also occurred in all of the specimens from the aluminum–rubber combination. The tensile strengths of the combinations having glass cloth facing material were reduced by this exposure more than the combinations having aluminum or plywood facings. The two sandwich panels having hard rubber cores were also considerably reduced in tensile strength following the weathering.

Sealing the edges of the panels did not appear to materially affect the tensile strength after an exposure of one year of weathering, when all the sandwich constructions were considered as one group.

Warp Measurements

The three sandwich constructions having plywood facings were seriously cupped and twisted after only 3 months of exposure, as shown in table 6. The amount of cupping of the panels was reduced during the winter months and then increased again during the summer months. The panels having aluminum facings were deformed more than those having glass cloth facings, but considerably less than the panels with plywood facings. The aluminum panels were quite sensitive to temperature differentials between the side in the shade (bottom) and the side in the sun (top). On days when the sun was bright, these panels would begin to flatten out as soon as they were removed to the shade, and became curved again when remounted on the exposure rack in the sun. The panels having plywood facings were permanently warped by the exposure, while those faced with aluminum and glass cloth returned approximately to their pre-exposure flatness after reconditioning to 65 percent relative humidity and 75° F.

The changes in weight of the exposure panels followed the seasonal moisture conditions, the balsa-glass cloth combination gaining the most weight during the early spring months, the combination bonded with rosin C reaching a maximum gain of about16 percent. The painting of the edges had very little effect on change in weight of the constructions. After reconditioning, the weights of the specimens were all within 2 percent of their original weights. The changes in tho dimensions of tho panels (length and width averaged, and thickness) were not considered to be excessive for any of the sandwich constructions.

APPENDIX I

Description of Resins and Adhesives

Resin A. A high-temperature-setting, high-viscosity, contact-pressure, laminating resin of the polyester type.

Resin B. A high-temperature-setting, low-viscosity, laminating resin of the styrene monomer, polyester type.

Resin C. A high-temperature-setting, high-viscosity, contact-pressure, laminating resin of the polyester type.

Resin D. A high-temperature-setting, low-viscosity, contact-pressure, laminating resin of the polyester type.

Resin E. A high-temperature-setting, Low-viscosity, laminating resin

Adhesive F. A high-temperature-setting, modified thermoplastic metal-to-wood glue.

Adhesive G. A high-temperature-setting, two-component resin with a thermo-setting liquid and thermoplastic powder.

Adhesive H. A high-temperature-setting, thermoplastic resin with thermosetting resin and pigment.

Adhesive M. 4 high-temperature-setting mixture of thermosetting resin and synthetic rubber.

Adhesive N. A high-temperature-setting, acid-catalyzed, phenolic resin.

Adhesive P. A room-temperature-setting resorcinol resin.

Adhesive R. A high-temperature-setting, melamine-resin adhesive.

Table 1.--Tensile strength of various sandwich constructions subjected to four controlled exposure conditions[1]

Sandwich construction		Bond symbol[2]	Controls		Effect on strength of exposure to --																							
Facing	Core		Strength	Core failure	24-hour water immersion		40-day water immersion		40-day water immersion reconditioned[1]		200° F. for 10 days		200° F. for 10 days reconditioned[1]		Equilibrium at 97 percent relative humidity		97 percent relative humidity, reconditioned[1]		One cycle[3]		Five cycles[3]		Ten cycles[3]		Ten cycles[3] reconditioned[1]	
					Percent of control strength	Core failure	Percent of control strength	Core failure	Percent of control strength	Core failure	Percent of control strength	Core failure	Percent of control strength	Core failure	Percent of control strength	Core failure	Percent of control strength	Core failure	Percent of control strength	Core failure	Percent of control strength	Core failure	Percent of control strength	Core failure	Percent of control strength	Core failure
			P.s.i.	Percent		Percent		Percent		Percent		Percent		Percent		Percent		Percent		Percent		Percent		Percent		Percent
Aluminum	Balsa	G	727	58	153	41	127	33	125	55	117	33	138	70	137	70	109	80	154	56	153	65	105	69	114	44
Aluminum	Balsa	F	169	18	60	4	52	15	121	16	54	48	129	26	63	10	98	14	109	22	78	13	112	28	52	19
Aluminum	Balsa	M + N	467	31	76	18	88	50	103	66	119	47	54	77	99	57	73	88	112	63	67	63	93	60	54	85
Plywood	Balsa	R	502	7	90	10	88	21	111	20	83	23	92	8	61	1	96	18	67	14	69	30	92	47	104	8
Glass cloth	Balsa	B	489	7	48	5	43	8	84	2	62	45	99	31	46	1	49	2	103	14	86	39	81	39	68	39
Glass cloth	Balsa	C	501	9	49	1	45	1	97	11	87	27	95	14	41	2	73	3	126	31	87	32	90	24	65	23
Glass cloth	Balsa	E	594	12	49	4	38	1	93	4	83	43	91	37	49	5	73	0	131	49	108	46	121	31	92	39
Glass cloth	Balsa	D	250	6	50	3	51	3	120	4	90	15	199	24	33	7	120	4	134	7	55	10	56	9	47	4
Aluminum	C.C.A.[4]	F	51	22	151	2	159	5	190	27	184	28	135	29	175	3	147	7	241	28	157	30	247	38	98	25
Aluminum	C.C.A.[4]	M + N	39	27	126	36	159	48	115	42	126	24	197	55	190	23	231	53	195	33	156	21	167	28	31	23
Glass cloth	C.C.A.[4]	B	115	34	124	11	84	9	126	13	116	20	127	33	113	3	149	8	124	26	121	10	122	10	106	6
Glass cloth	C.C.A.[4]	C	166	19	104	17	79	7	124	38	90	42	132	54	87	4	155	66	131	61	84	53	129	45	116	23
Glass cloth	C.C.A.[4]	D	276	4	79	34	67	3	109	91	84	92	93	92	55	2	105	93	87	90	79	43	107	47	79	38

[1] Each figure represents the average results of 6 to 9 individual tests. All specimens initially in equilibrium with 75° F., and 65 percent relative humidity.
[2] See Appendix I for description of adhesives used to bond aluminum and plywood facings to the cores, and laminating resins used to wet-laminate the glass cloth facings.
[3] One cycle consisted of the following consecutive treatments: 24 hours at 175° F., - 75 percent relative humidity, 24 hours at -20° F., 24 hours at 175° F., and 24 hours at -20° F.
[4] Cellular cellulose acetate.

Table 2.--Edgewise compressive strength of various sandwich constructions subjected to four controlled exposure conditions

Sandwich construction: Facing	Sandwich construction: Core	Bond symbol[1]	Controls: Low	Controls: High	Controls: Average of seven tests	Effect on strength of exposure[2] to --: Water immersion for 40 days	Water immersion for 40 days, then reconditioned[2]	200° F. for 10 days	200° F. for 10 days, then reconditioned[2]	97 percent relative humidity	97 percent relative humidity, then reconditioned[2]	Ten cycles[3]	Ten cycles,[3] then reconditioned[2]
			Lb. per in. of width	Lb. per in. of width	Lb. per in. of width	Percent of control strength	Percent of control strength	Percent of control strength	Percent of control strength	Percent of control strength	Percent of control strength	Percent of control strength	Percent of control strength
Aluminum	Balsa	G	1,974	2,606	2,367	85	85	84	91	91	85	92	91
Aluminum	Balsa	F	855	970	911	111	115	120	109	150	109	127	105
Aluminum	Balsa	M + N	972	1,612	1,245	123	121	102	90	135	136	141	145
Plywood	Balsa	R	860	916	887	49	98	127	115	58	93	144	106
Glass cloth	Balsa	B	665	1,014	924	33	85	56	88	38	72	90	81
Glass cloth	Balsa	C	468	740	620	33	99	89	108	46	92	130	92
Glass cloth	Balsa	E	653	755	709	27	68	96	76	41	64	102	69
Glass cloth	Balsa	D	431	586	499	22	101	55	92	21	80	97	[4]45
Aluminum	C.C.A.[5]	F	872	1,095	966	96	87	99	93	123	107	109	87
Aluminum	C.C.A.[5]	M + N	1,005	1,368	1,136	81	84	58	72	105	78	87	85
Glass cloth	C.C.A.[5]	B	723	850	787	47	93	87	96	55	88	101	85
Glass cloth	C.C.A.[5]	C	394	746	583	47	100	108	118	53	101	131	110
Glass cloth	C.C.A.[5]	D	364	522	436	43	135	87	157	36	123	150	80

[1]See Appendix I for description of adhesives and resins.

[2]All specimens originally conditioned to 75° F., 65 percent relative humidity.

[3]One cycle consisted of the following consecutive treatments: 24 hours at 175° F. - 75 percent relative humidity, 24 hours at -20° F., 24 hours at 175° F., and 24 hours at -20° F.

[4]Four specimens in the reconditioned group had delaminated facings.

[5]Cellular cellulose acetate.

Z M 81263 F

Table 3.--Summary of weather conditions for the period of July 1, 1946 to June 30, 1947[1]

Month	Temperatures				Average relative humidity	Precipitation		Possible sunshine	
	Maximum	Minimum	Mean	Normal mean		Total	Normal	Mean	Normal
	° F.	° F.	° F.	° F.	Percent	Inches	Inches	Percent	Percent
July	94	55	72.9	72.1	66	1.23	3.88	75	70
August	92	47	68.8	69.8	67	2.01	3.21	71	64
September	83	41	62.4	62.4	78.5	4.60	3.72	68	57
October	81	34	55.4	50.3	73	1.81	2.43	58	51
November	59	13	38.0	35.2	77.5	1.63	1.78	38	31
December	60	-10	27.0	22.8	75.5	1.61	1.63	40	36
January	55	-17	23.1	16.7	78	1.97	1.38	50	43
February	48	-7	16.8	19.1	75.5	.12	1.50	62	43
March	62	11	30.4	30.6	74	1.33	2.07	64	51
April	72	26	44.4	45.4	74	4.86	2.77	48	53
May	78	28	52.6	57.6	71	4.20	3.85	58	57
June	93	38	63.8	67.2	74	6.45	3.76	57	63

[1] Data from official U. S. Weather Bureau records.

Table 4.--Edgewise compressive strength of various sandwich construction exposed for 1 year to the weather

Sandwich construction: Facing	Sandwich construction: Core	Bond symbol[1]	Original controls: Low	Original controls: High	Original controls: Average of 7 tests	Controls - tested after 32 months at 75° F. and 62 percent R.H.: Low	Controls - tested after 32 months: High	Controls - tested after 32 months: Average of 7 tests	Controls - tested after 32 months: Percent of original control strength	Effect of weathering (Specimens from small panels): Edges not sealed (Average of 8 tests)	Effect of weathering (small panels): Edges sealed (Average of 8 tests)	Effect of weathering (small panels): Grand average	Effect of weathering (small panels): Percent of original control strength	Effect of weathering (Specimens from large panels): Edges not sealed (Average of 4 tests)	Effect of weathering (large panels): Edges sealed (Average of 4 tests)	Effect of weathering (large panels): Grand average	Effect of weathering (large panels): Percent of original control strength	Percent of all weathered specimens to all control strengths
			Lb. per in. of width	Lb. per in. of width	Lb. per in. of width	Lb. per in. of width	Lb. per in. of width	Lb. per in. of width	Lb. per in. of width	Lb. per in. of width	Lb. per in. of width	Lb. per in. of width	Lb. per in. of width	Lb. per in. of width	Lb. per in. of width	Lb. per in. of width	Lb. per in. of width	
Aluminum	Balsa	G	1,974	2,606	2,367	1,831	2,637	2,190	92	2,158	2,271	2,215	94	2,385	2,415	2,400	101	100
Aluminum	Balsa	F	855	970	911	488	985	782	86	1,503	1,585	1,544	169	1,935	1,523	1,730	190	190
Aluminum	Balsa	M + N	972	1,612	1,245	803	1,644	1,163	93	1,690	1,843	1,766	142	1,947	1,044	1,494	120	139
Plywood	Balsa	R	860	916	887	843	886	866	98	838	881	860	97	764	785	774	87	95
Glass cloth	Balsa	A	745	1,054	896	745	974	869	97	771	650	710	79	721	824	773	86	83
Glass cloth	Balsa	B	665	1,014	924	743	1,026	882	96	811	670	740	80	809	805	807	87	84
Glass cloth	Balsa	C	468	740	620	383	697	558	90	572	564	568	92	384	384	384	62	86
Glass cloth	Balsa	E	653	755	709	596	750	679	96	634	618	626	88	531	548	540	76	86
Glass cloth	Balsa	D	431	586	499	430	512	468	94	486	508	497	100	678	626	652	131	113
Aluminum	C.C.A.[2]	H + P	775	1,522	1,178	598	1,127	850	72	1,325	1,202	1,254	106	931	1,487	1,209	103	122
Aluminum	C.C.A.[2]	F	872	1,095	966	724	1,254	1,003	104	1,276	1,089	1,182	122	1,596	1,485	1,540	159	132
Aluminum	C.C.A.[2]	M + N	1,005	1,368	1,136	1,041	1,222	1,153	101	1,225	1,168	1,196	105	1,386	1,407	1,396	123	110
Plywood	C.C.A.[2]	P	875	933	898	835	930	871	97	836	818	827	92	818	836	827	92	94
Glass cloth	C.C.A.[2]	A	777	938	824	731	907	817	99	630	611	620	75	727	758	744	90	81
Glass cloth	C.C.A.[2]	B	723	850	787	679	854	789	100	592	619	605	77	841	891	866	110	88
Glass cloth	C.C.A.[2]	C	394	746	583	512	765	690	118	538	529	534	92	652	675	664	114	91
Glass cloth	C.C.A.[2]	D	364	522	436	348	707	443	102	605	619	613	141	681	528	605	139	139
Aluminum	C.H.R.[3]	H + P	704	977	842	430	809	610	72	919	955	937	111	951	1,081	1,016	121	133
Plywood	C.H.R.[3]	P	687	927	827	729	911	828	100	792	764	778	94	756	776	766	93	93
Glass cloth	C.H.R.[3]	A	374	1,001	719	289	905	644	90	440	626	533	74	739	770	755	105	89
Grand averages of all constructions										932	930			1,012	982			

[1]See Appendix I for description of adhesives and resins.

[2]Cellular cellulose acetate

[3]Cellular hard rubber.

Z M 81264 F

Table 5.--Tensile strength of various sandwich constructions subjected to 1 year of exposure to the weather

Sandwich construction		Bond symbol[1]	Control tests				Final tests						
Facing	Core		Low	High	Average of 10 tests	Average core failure	Low	High	Edges not sealed (Average of 10 tests)	Edges sealed (Average of 10 tests)	Grand average (of 20 tests)	Average core failure	Percent of control strength
			P.s.i.	P.s.i.	P.s.i.	Percent	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	Percent	
Aluminum	Balsa	G	1,590	2,525	2,015	19	1,464	2,420	1,979	1,772	1,875	58	93
Aluminum	Balsa	F	10	260	103	20	0	257	104	119	111	11	108
Aluminum	Balsa	M+N	660	1,315	936	72	390	1,240	862	739	801	58	86
Plywood	Balsa	R	127	458	321	19	85	890	413	563	495	36	154
Glass cloth	Balsa	A	296	687	498	66	159	651	487	400	443	19	89
Glass cloth	Balsa	B	521	825	700	1	290	770	657	561	612	1	87
Glass cloth	Balsa	C	225	500	374	28	20	485	127	386	278	21	74
Glass cloth	Balsa	E	435	900	730	50	485	1,060	835	654	744	28	102
Glass cloth	Balsa	D	340	575	452	24	210	610	484	495	489	18	108
Aluminum	C.C.A.[2]	H+P	--	--	--	--	10	197	23	118	70	2	--
Aluminum	C.C.A.[2]	F	16	83	50	27	22	231	98	98	98	51	196
Aluminum	C.C.A.[2]	M+N	--	--	--	--	23	100	51	51	51	89	--
Plywood	C.C.A.[2]	P	178	325	277	100	210	330	305	266	287	97	104
Glass cloth	C.C.A.[2]	A	83	253	167	46	108	289	166	210	188	82	113
Glass cloth	C.C.A.[2]	B	156	235	204	26	90	232	136	174	155	25	76
Glass cloth	C.C.A.[2]	C	187	311	251	64	86	282	187	175	181	56	72
Glass cloth	C.C.A.[2]	D	230	290	265	99	77	233	125	165	145	74	55
Plywood	C.H.R.[3]	P	79	181	130	98	34	113	63	79	71	99	55
Glass cloth	C.H.R.[3]	A	134	168	146	100	4	115	85	52	67	94	46
					Grand averages of all constructions				378	372			

[1]See Appendix I for description of adhesives and resins.

[2]Cellular cellulose acetate.

[3]Cellular hard rubber.

Z M 81265 F

Table 6.—Effect of exposure to weather on weight, dimensions and flatness of various sandwich constructions.

Sandwich construction: Facing	Sandwich construction: Core	Bond symbol[1]	Edge condition	Change after 3 months (Oct. 1946): Weight	Width and length	Thickness	Amount of warp[2]: Cupping	Amount of warp[2]: Twist	Change after 6 months (Jan. 1947): Weight	Width and length	Thickness	Amount of warp[2]: Cupping	Amount of warp[2]: Twist	Change after 9 months (Apr. 1947): Weight	Width and length	Thickness	Amount of warp[2]: Cupping	Amount of warp[2]: Twist	Change after 12 months (July 1947): Weight	Width and length	Thickness	Amount of warp[2]: Cupping	Amount of warp[2]: Twist	Change after reconditioning to 75° F. and 65% R.H.: Weight	Width and length	Thickness	Amount of warp[2]: Cupping	Amount of warp[2]: Twist
				Percent	Inch	Inch	Inch	Inch	Percent	Inch	Inch	Inch	Inch	Percent	Inch	Inch	Inch	Inch	Percent	Inch	Inch	Inch	Inch	Percent	Inch	Inch	Inch	Inch
Aluminum	Balsa	G	Unpainted	0.4	0.00	-0.002	0.010	0.014	0.9	0.01	-0.001	0.008	0.019	1.0	0.02	0.000	-0.018	-0.030	0.7	0.00	0.000	0.006	-0.002	0.7	0.01	0.000	-0.004	0.002
Aluminum	Balsa	G	Painted	0.2	.02	-.001	.011	.010	.4	.04	.001	.007	.014	.5	.02	.003	-.017	-.037	.3	.02	.003	.012	-.003	0.5	.02	.001	.000	-.002
Aluminum	Balsa	F	Unpainted	0.9	.00	-.004	.016	.024	2.4	.00	-.002	.012	.017	2.7	-.03	.000	.015	-.002	2.1	-.02	-.001	.015	.011	0.2	-.02	-.002	-.002	-.006
Aluminum	Balsa	F	Painted	5.4	-.10	.001	.018	.023	5.8	.02	.001	.010	.021	5.7	.00	.003	.014	.003	4.4	.01	.003	.021	.024	1.6	.01	.005	-.002	-.002
Aluminum	Balsa	M+N	Unpainted	0.9	-.02	-.002	.004	.021	1.2	-.02	-.001	-.004	.015	1.6	-.02	.000	-.003	.006	1.5	-.02	.007	.006	.012	0.7	-.02	-.002	-.012	.005
Aluminum	Balsa	M+N	Painted	2.6	.02	.002	.012	.014	3.0	.03	.002	.006	.012	3.3	.00	.004	.007	-.004	3.2	.02	.004	.012	.003	1.1	.02	.004	-.001	.002
Plywood	Balsa	R	Unpainted	-0.5	.00	.001	-.098	-.189	3.1	.02	.003	-.009	-.012	3.3	.00	.004	-.045	-.063	-0.4	.00	.001	-.105	-.235	-1.1	.00	.000	-.033	-.058
Plywood	Balsa	R	Painted	0.3	-.02	.002	-.100	-.180	3.9	.02	.003	-.002	.001	3.3	.00	.004	-.046	-.070	-0.3	-.04	.000	-.102	-.222	-0.1	-.02	.000	-.046	-.068
Glass cloth	Balsa	A	Unpainted	5.1	.00	.001	-.029	-.060	6.3	.02	.000	.020	.034	12.3	.00	.001	-.016	-.025	8.2	.00	.000	-.015	-.056	0.8	.00	.000	.016	.031
Glass cloth	Balsa	A	Painted	0.9	.02	.000	-.011	-.016	6.2	.04	.000	.015	.027	10.5	.02	.001	-.014	-.028	8.7	.03	.001	-.033	-.058	1.6	.00	.000	.012	.020
Glass cloth	Balsa	B	Unpainted	0.6	-.01	.000	.002	.003	6.4	.01	-.001	.018	.022	9.0	.00	.000	.002	-.002	5.0	-.01	.001	-.002	-.010	0.9	-.02	-.001	.012	.016
Glass cloth	Balsa	B	Painted	0.1	.00	.000	-.010	-.018	9.5	.02	.001	.014	.026	14.7	.01	.001	-.004	-.009	7.2	.00	.001	-.009	-.020	0.8	-.02	.000	.008	.010
Glass cloth	Balsa	C	Unpainted	-0.2	-.02	.000	-.002	-.010	12.1	.01	.001	.008	.018	16.3	-.02	.001	-.014	-.021	7.2	-.01	.001	-.022	-.038	0.3	-.02	-.001	.002	.012
Glass cloth	Balsa	C	Painted	0.0	-.02	—	-.003	-.012	9.6	.00	.001	.012	.016	16.0	-.04	.002	-.018	-.026	7.8	-.03	.002	-.026	-.040	0.5	-.03	.001	.002	.004
Glass cloth	Balsa	E	Unpainted	-1.6	-.01	-.001	.000	.000	4.2	.02	-.001	.010	.012	2.4	.00	-.001	-.021	-.038	-0.4	-.01	.000	-.017	-.035	-0.7	.00	-.001	.006	.007
Glass cloth	Balsa	E	Painted	-1.9	.00	.000	.000	-.002	1.3	.02	.000	.008	.009	1.2	.01	.001	-.018	-.035	-0.4	.00	.001	-.025	-.052	-0.3	-.01	-.001	.006	.010
Glass cloth	Balsa	D	Unpainted	-0.6	.00	.000	-.002	-.024	7.1	.00	.001	.014	.006	11.6	-.01	.001	-.004	.028	4.9	.00	.001	-.010	-.028	0.1	-.01	.000	-.003	-.002
Glass cloth	Balsa	D	Painted	-0.2	.01	.001	-.002	-.016	7.1	.02	.001	.009	.016	12.0	.00	.002	-.007	-.018	5.0	.00	.001	-.015	-.038	0.3	-.02	.000	-.002	-.006
Aluminum	C.C.A.[3]	R+P	Unpainted	-0.2	.00	-.005	.010	.018	0.7	.00	-.001	-.012	.004	1.3	-.02	-.002	.008	.000	3.4	-.01	.014	.050	.064	-0.4	.00	.017	.038	.062
Aluminum	C.C.A.[3]	R+P	Painted	-0.1	.02	-.003	.023	.088	0.4	.02	-.004	.008	.014	0.7	.00	-.001	.012	.008	0.2	-.01	-.003	.040	.044	-0.4	.02	-.004	.047	.078
Aluminum	C.C.A.[3]	F	Unpainted	0.3	-.02	-.002	.028	.032	1.2	.02	-.003	-.004	-.012	2.0	-.02	.001	.011	.015	1.1	-.03	.000	.022	.016	0.6	-.01	-.003	.016	.036
Aluminum	C.C.A.[3]	F	Painted	0.5	.00	.001	.022	.022	0.9	.02	.004	-.013	-.024	1.2	-.01	.004	.008	.013	0.7	-.01	.007	.016	.024	0.8	-.01	.000	-.002	-.005
Aluminum	C.C.A.[3]	M+N	Unpainted	0.1	.00	-.004	.034	.056	0.9	.00	-.003	.019	.126	1.0	-.02	-.001	.014	.024	0.7	-.02	.000	.030	.046	0.6	-.01	-.001	.008	.012
Aluminum	C.C.A.[3]	M+N	Painted	0.0	.02	-.001	.048	.036	0.3	.03	.000	.045	.076	0.5	.00	.002	.029	.021	0.2	-.01	.001	.040	.032	0.6	.00	.001	.018	.000
Plywood	C.C.A.[3]	P	Unpainted	-0.8	.01	-.001	-.099	-.210	2.6	.04	.003	-.003	-.043	2.1	.02	.002	.071	-.151	-1.9	-.01	-.003	-.107	-.212	-1.9	.00	-.002	-.012	-.029
Plywood	C.C.A.[3]	P	Painted	0.0	.02	.003	-.108	-.220	3.2	.05	.005	.022	.019	2.3	.02	.006	.066	-.144	-1.3	.02	.002	-.100	-.209	-0.9	.02	.000	-.012	-.036
Glass cloth	C.C.A.[3]	A	Unpainted	0.5	.00	.000	.004	.002	2.1	.03	.004	.023	.034	2.1	.00	.003	-.004	-.012	1.0	-.02	.002	-.014	-.034	0.6	.00	.001	.011	.020
Glass cloth	C.C.A.[3]	A	Painted	0.7	.04	.001	.002	-.002	2.1	.04	.004	.026	.042	2.0	.02	.005	-.001	-.008	0.9	.02	.003	-.017	-.041	0.9	.03	.002	.014	.024
Glass cloth	C.C.A.[3]	B	Unpainted	-0.3	.00	-.009	-.008	-.016	1.3	.02	-.007	-.007	-.004	1.6	.00	-.006	-.020	-.028	0.9	.00	-.008	-.012	-.017	0.3	.02	-.008	-.002	.004
Glass cloth	C.C.A.[3]	B	Painted	0.0	.02	.000	-.010	-.030	1.1	.03	.002	-.005	-.010	1.2	.00	.003	-.012	-.034	0.3	.00	.000	-.008	-.030	0.6	.02	.001	.002	.002
Glass cloth	C.C.A.[3]	C	Unpainted	-0.4	.00	.000	.000	-.010	2.8	.02	.003	.014	.020	2.1	-.02	.003	-.012	-.032	1.1	-.02	.000	-.030	-.066	-0.2	-.02	-.002	.004	-.003
Glass cloth	C.C.A.[3]	C	Painted	0.2	.02	.002	.000	-.021	1.7	.04	.004	.017	.032	1.4	.00	.003	-.006	-.014	0.2	.00	.002	-.017	-.041	0.4	.02	.001	.001	.004
Glass cloth	C.C.A.[3]	D	Unpainted	0.6	.01	.004	-.014	-.014	1.7	.00	.006	-.002	.001	1.7	.02	.006	-.015	-.036	0.9	-.02	.005	-.015	-.030	0.4	.00	-.006	-.006	-.001
Glass cloth	C.C.A.[3]	D	Painted	0.5	.02	.002	-.014	-.032	1.6	.03	.003	.000	.000	1.5	.00	.005	-.014	-.030	1.0	.00	.004	-.023	-.047	0.7	.02	.001	-.006	-.018
Aluminum	C.H.R.[4]	H+P	Unpainted	-0.4	.01	.004	.010	.014	-0.2	-.12	.006	.002	.008	-0.2	-.01	.005	.014	.018	-0.6	-.02	.005	.004	.044	-0.9	.02	.006	.001	.014
Aluminum	"	H+P	Painted	0.0	.00	-.002	-.002	-.014	0.1	.01	.002	-.002	-.014	0.2	-.01	.000	.019	-.002	0.3	.00	.000	.033	-.003	0.1	.00	-.002	.010	.005
Plywood	C.H.R.[4]	P	Unpainted	-1.0	.00	.003	-.149	-.256	2.5	.01	.005	-.063	-.098	1.1	.00	.005	-.156	-.264	-1.8	-.02	.004	-.212	-.364	-1.9	-.02	.000	.136	-.212
Plywood	C.H.R.[4]	P	Painted	0.1	.02	.003	-.089	-.172	2.6	.06	.006	-.041	-.068	1.5	.02	.006	-.095	-.185	-1.2	-.01	.003	-.128	-.234	-0.6	.01	—	-.058	-.120
Glass cloth	C.H.R.[4]	A	Unpainted	0.0	.12	.000	-.010	-.030	0.7	.13	-.001	.021	.045	0.7	.12	.000	-.007	-.020	0.2	.10	.001	-.008	-.022	0.2	.06	.000	.045	.010
Glass cloth	C.H.R.[4]	A	Painted	0.2	.01	-.001	-.042	-.083	0.9	.03	-.001	.012	.009	0.9	.03	.001	-.020	-.021	0.4	.02	.000	-.024	-.058	0.4	.01	.001	.002	-.032

[1] See Appendix I for description of adhesives and resins.
[2] Indicates concave upward.
[3] Cellular cellulose acetate
[4] Cellular hard rubber

Z M 81266 F

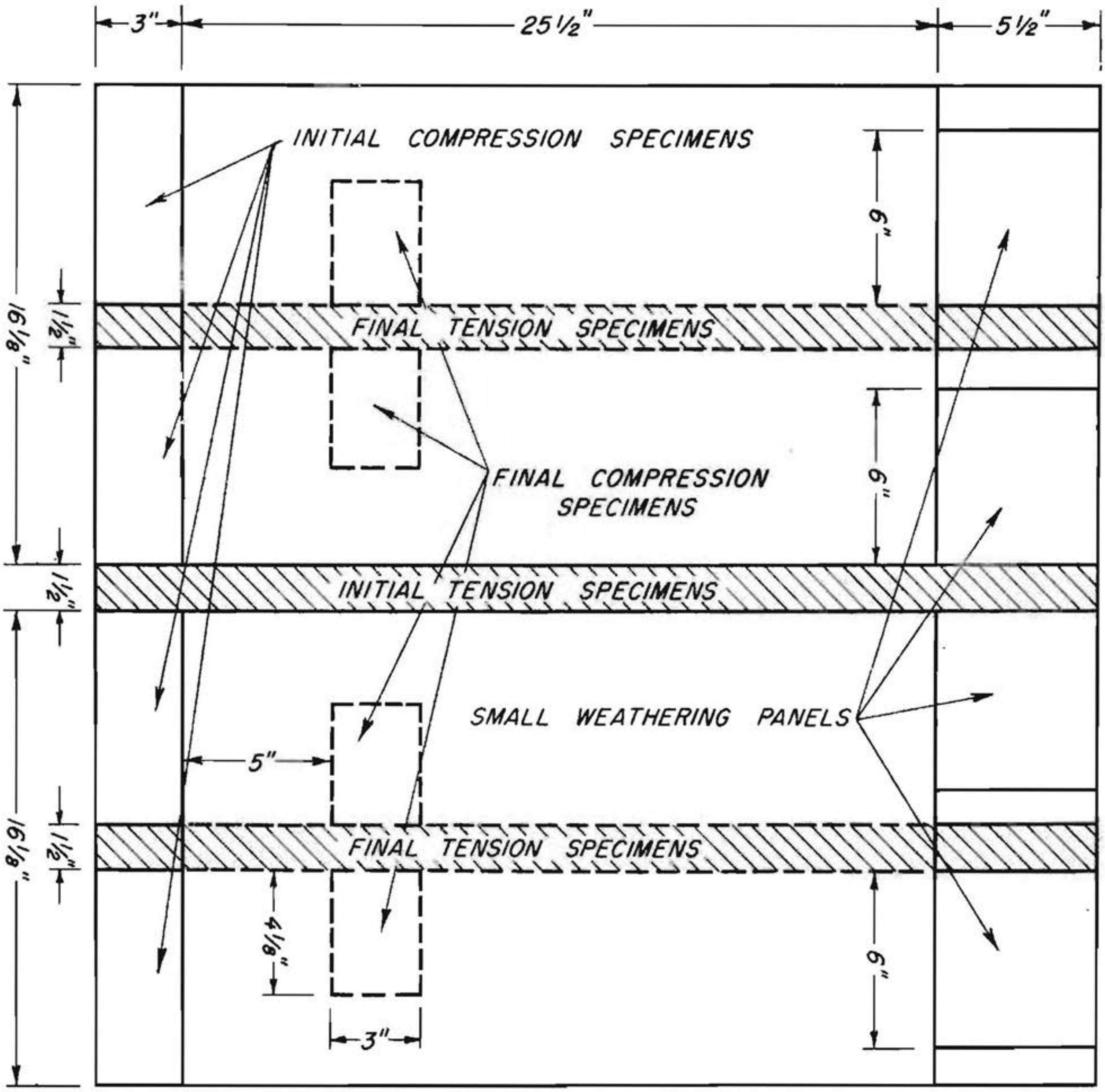

Figure 1.--The extruded length of the rubber and cellulose acetate was oriented in the same direction as the grain of the face material. For balsa cores the narrow dimensions of the individual pieces were oriented in the same direction as the grain of the face material. The shaded areas on the aluminum-faced panels were coated with a metal priming cement that was cured before assembly of the panels. The two 16-1/8 by 25-1/2-inch weathering panels were cut on the dotted linea after exposure.

ZM81260F

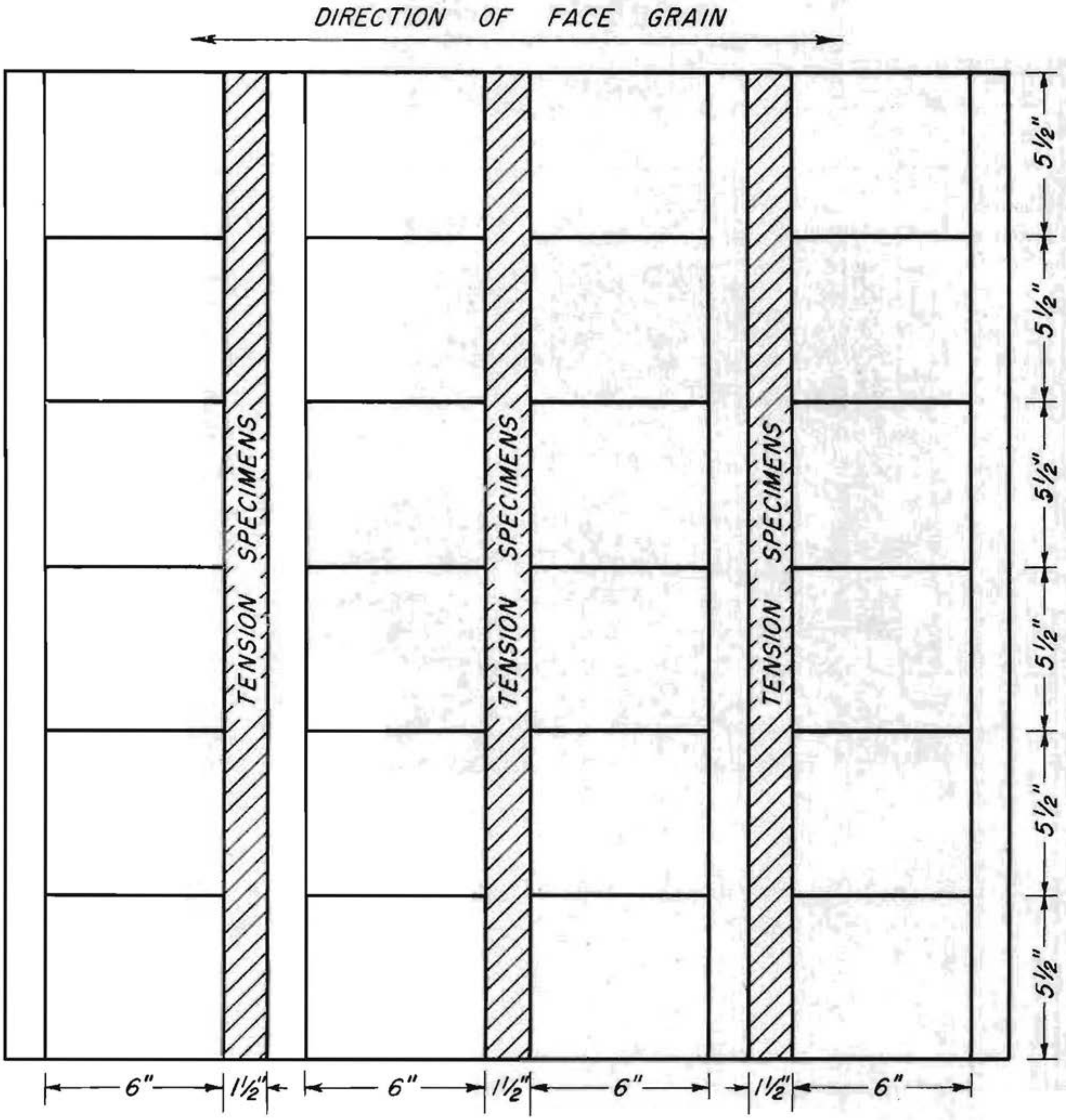

Figure 2.--The extruded length of the rubber and cellulose acetate was oriented in the same direction as the grain of the face material. For balsa cores the narrow dimensions of the individual pieces were oriented in the same direction as the grain of the face material. The shaded areas on the aluminum-faced panels were coated with a metal priming cement that was cured before assembly of the panels.

ZM81261F

Figure 3.--High-viscosity laminating resin being spread on glass cloth with a mechanical spreader.

ZM72146F

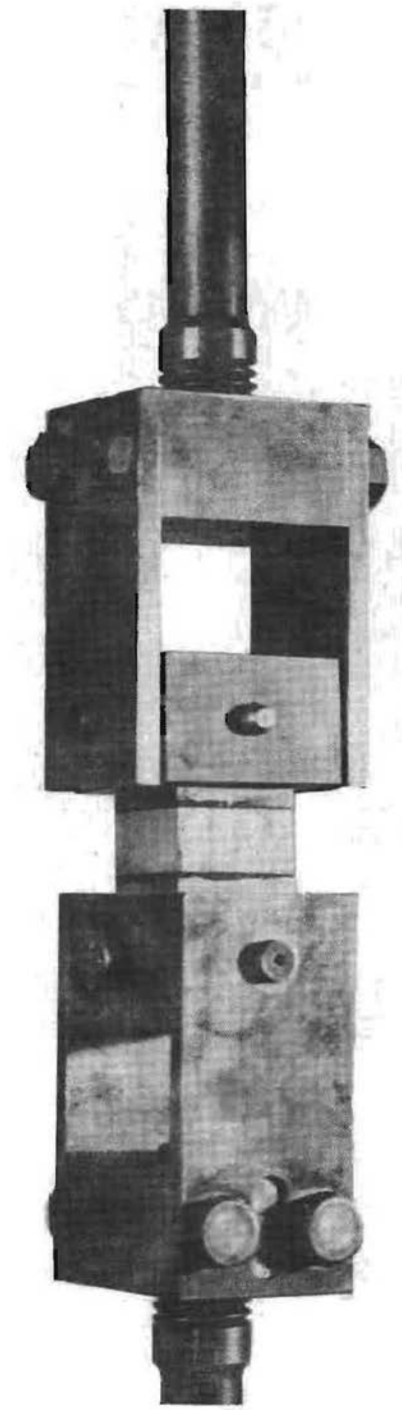

Figure 4. --Forest Products Laboratory tension specimen for sandwich materials assembled in testing apparatus.

ZM64125F

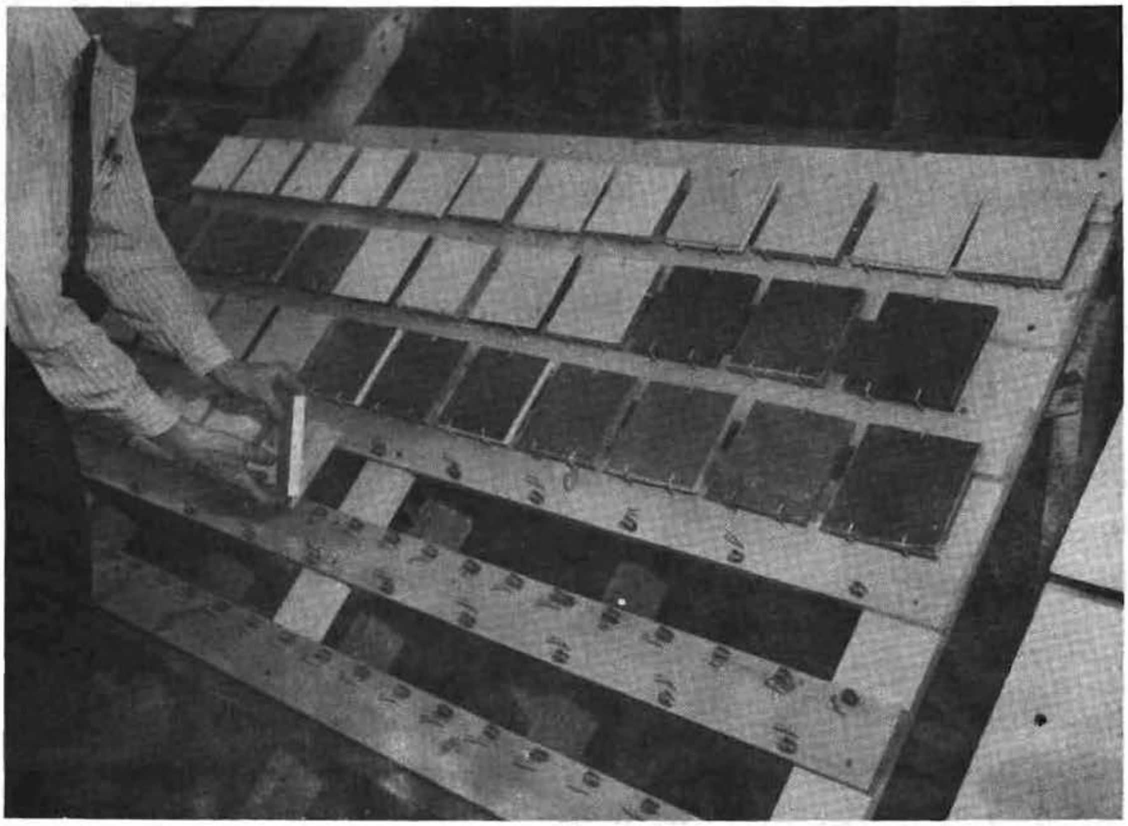

Figure 5.--Racks used for mounting sandwich panels for exposure to weather, showing the method of attaching specimens.

ZM61240F

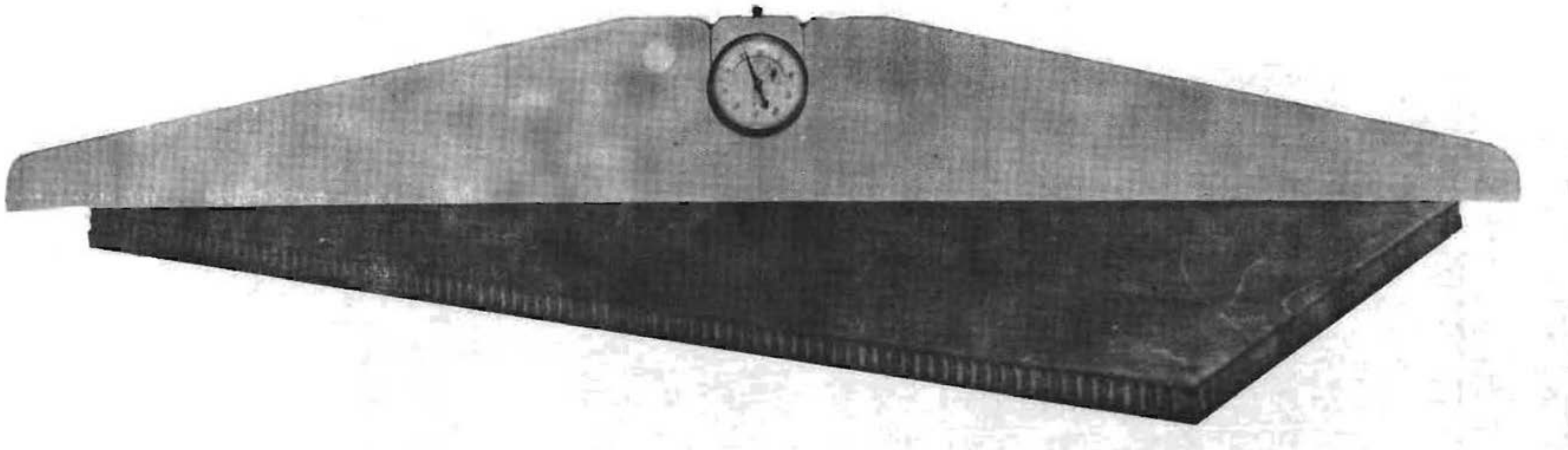

Figure 6.--Straight edge and dial indicator used to determine cupping and twisting of large weathering panels. Panel shown has a paper honeycomb core and is not one of the series tested for this report.

ZM80268F

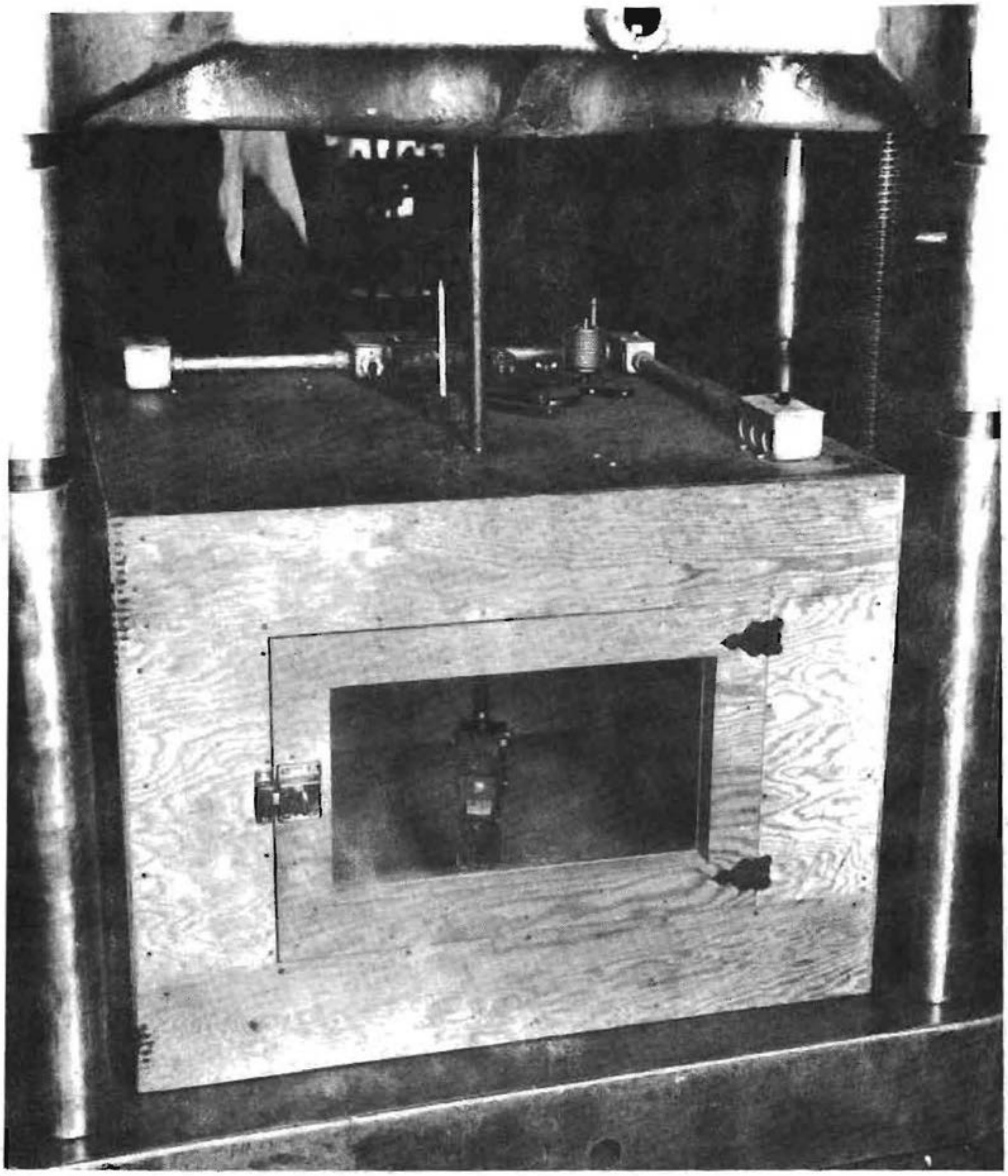

Figure 7.--Large insulated and heated box used in making tests at high temperature. A tension specimen shown in place.

ZM67069F