FABRICATION OF LIGHTWEIGHT SANDWICH PANELS OF THE AIRCRAFT TYPE

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UNITED STATES DEPARTMENT OF AGRICULTURE
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FABRICATION OF LIGHTWEIGHT SANDWICH PANELS OF THE AIRCRAFT TYPE[1]

By

BRUCE G. HEEBINK, Engineer
ALVIN A. MOHAUPT, Technologist
and
JOHN J. KUNZWEILER, Technologist

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Introduction

The Army-Navy-Civil Subcommittee on Wood Aircraft Structures early in 1944 requested the Forest Products Laboratory to fabricate and test the panels necessary to establish design criteria for sandwich constructions. In January 1945, the ANC Subcommittee requested that the development of fabrication techniques for sandwich panels be considered a part of the sandwich research program at the Forest Products Laboratory and that all observations and techniques should be recorded.

The purpose of this report is to describe the materials used, to record the fabricating procedures adopted, and to summarize the techniques that were tried and found impracticable or unworkable in the production of the required test panels.

Preparation of Cores

Balsa

An attempt was made to select the balsa within a density range of 5 to 8 pounds per cubic foot on a 12 percent equilibrium-moisture-content basis. Previously, balsa in a range of 6 to 9 pounds per cubic foot was used. The material was received full 3 inches thick, surfaced on two opposite sides, in random widths and lengths. The specifications used in its procurement are given in Appendix 1. If necessary, the material as received was first kiln dried to a moisture content approximately in equilibrium with the workrooms (5 to 7 percent when the work was done during the winter months).

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[1]This is one of a series of reports prepared by the Forest Products Laboratory relating to the use of wood in aircraft. Results here reported are preliminary and may be revised as additional data become available.

Density determinations were made by cutting 1/2-inch cross sections from each end of every plank. If the two samples fell within the acceptable limits, the plank was used. If, however, one end was too heavy or too light, a 30-inch length was cut from that end and another density check made. If one end was too heavy and the other too light, sections were cut from each end and further density measurements were made. If both ends were too light or too heavy, the entire plank was rejected.

These cross-sectional density checks merely established the average density of the plank at the point of cutting, but it was assumed that these average values were applicable to the whole plank. It was found, however, that the density often doubled from one growth ring to the next. Rejections due to unacceptable density were 20 to 50 percent of three shipments of balsa.

Planks or portions of planks with obvious defects, such as checks or rot, were also rejected before processing further. Acceptable material was cut to 30-inch lengths and these were accurately jointed and planed to rectangular shape. They were then cut into end-grain slabs of the desired thickness on a 14-inch circular cross-cut saw running at 3,600 revolutions per minute and having about 5-1/2 teeth per inch. By keeping the saw in good condition and removing all end play from the arbor, it was possible to produce acceptable slabs by the method shown in figure 1. Slabs were inspected at the saw by calipering each corner for thickness. Tolerances of ± 0.003 inch were permitted. Rejections for thickness variations were normally less than 10 percent on this basis.

In spite of the carefully controlled technique used in sawing the balsa slabs, the end grain surfaces of the slabs were occasionally slightly wavy. The growth rings of higher density produced the ridges and the rings of lower density formed the valleys. Determinations made on one slab revealed a density of about 9.5 pounds per cubic foot in a high-density ring and 5.3 pounds per cubic foot in the adjacent low-density ring one-half inch away. Figure 2 shows a slab that had very noticeable ridges, and figure 3 is a photomicrograph of the sawn surface of a similar slab showing the two types of surfaces. Further investigations of this condition have shown that balsa wood that produces a granular or pithlike break when a blunt instrument is drawn across the end surface in the radial direction so as to tear out a groove has a density of less than 5 pounds per cubic foot. Such balsa is sometimes termed "corcho."[2]

Further investigation showed that in densities under 5 pounds per cubic foot, balsa wood has very few long fibers and a large number of short fibers with large diameters and thin walls. Wood which does not have the typical "corcho" tear has large percentages of long fibers with thicker walls and smaller diameters, hence its greater specific gravity.

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[2] "Corcho" is a Spanish term meaning "corklike."

The result of this investigation indicated that so-called "corcho" and low-density balsa (specific gravity under 0.080) are synonymous. Figure 4 shows the effect of cutting balsa planks containing corcho with a circular saw. The saw cuts have a distinct indentation where they are made across wide bands of "corcho" or low-density material.

Cores of the sizes desired were originally made by gluing these slabs (about 3 by 5 inches) together by hand and weight pressure with animal glue. Later they were assembled into panels with the use of a high-frequency edge-gluing machine, as shown in figure 5, with phenolic and resorcinol adhesives. After assembling, the cores were lightly sanded with fine sandpaper on a wood block, to remove glue squeeze-out and other minor surface imperfections, and were trimmed to size. A typical end-grain balsa core is shown in figure 6. No attempt was made to match cores or to have all the slabs in one core from the same plank except in special cases.

Cellular Cellulose Acetate[3]

The cellular cellulose acetate was received in the form of continuously extruded bars, approximately 5/8 by 2-5/8 to 5-1/2 inches in cross section (fig. 7), and included about 3 percent of chopped-glass fiber. The density was between 6.0 and 6.8 pounds per cubic foot, after the skins were removed.

The extruded bars, which were easily machined by ordinary woodworking methods, were dimensioned by jointing one side and edge before they were ripped to proper thickness on a circular saw. It was later found that a wood-cutting band saw running at 4,000 feet per minute and having five teeth per inch produced an equally smooth surface and resulted in less waste in saw kerf (fig. 8).

Strips of the proper thickness (within tolerances of ±0.005 inch) were at first glued together with animal glue to the desired size. Later they were assembled on the high-frequency edge-gluing machine with phenolic or resorcinol adhesives.

Cellular Hard Rubber[4]

The cellular hard rubber was received in the form of slabs, approximately 1-1/2 by 20 by 36 inches. It was an expanded, hard, synthetic, sponge rubber, black in color (fig. 9). Its density, with the outer skin and one-eighth inch of higher density material removed, was from 6.2 to 7.2 pounds per cubic foot. Ordinary woodworking procedures were used in cutting this rubber to dimensions desired. It could be planed to a minimum thickness of one-fourth inch by feeding it on a back-up board through a planer if the feed-roll and chip-breaker pressures were reduced.

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[3] Appendix III Note 22.

[4] Appendix III Note 21.

Rubber cores were prepared by removing the outer one-eighth inch on a jointer and by planing to proper thickness after resawing on a band saw. One-sixteenth inch on each side was allowed for the planing to remove feed roll marks. Cores longer than the size of the slabs were first fabricated by edge gluing with animal glue. Later the cores were made using a high-frequency edge-gluing machine with phenolic or resorcinol adhesives.

Paper Honeycomb

All the paper honeycomb material[5] used in this study was made at the Forest Products Laboratory. The material was produced by impregnating 4.5-ail kraft paper of 12-inch width with about 10 percent of a phenolic resin (T),[6] thinned with alcohol and water. This preliminary treatment was done by passing the paper around a roller partly submerged in the resin, and then through a drier about 12 feet long at 140° C. at a speed of about 3 feet per minute. The phenolic-treated paper was then put through a "B-flute" corrugating machine, cut to 40-inch lengths, and nested with other sheets. The nesting is important to produce sheets as similar as possible so that the corrugations line up when the sheets are assembled in a block. These nested sheets were cured in an oven at 125° C. for 5 to 6 hours.

The individual corrugated sheets were impregnated with a low-viscosity, laminating resin (B),[7] to a 55 percent resin content by laying the sheets on a piece of plate glass covered with a uniform film of the resin, The sheets were then placed on a jig that had heating elements on the side to cure the resin partially and thus reduce slippage when the corrugated sheets were laid node to node. It also prevented the resin from running to one side and thereby producing a block of nonuniform density. Sufficient sheets were laid. together to produce a block from 2-1/2 to 2-3/4 inches thick. The use of blocks of greater thicknesses resulted in greater variations than desired when cut into thin sections, and the thicker blocks could not be cut with a circular saw. The approximate dimensions of the blocks were 2-1/2 by 12 by 40 inches with the cells running in the 12-inch direction. In this form, the blocks were given a final cure in an oven provided with forced-air circulation at 120° to 125° C. for 2-1/2 hours,

The paper honeycomb blocks were trimmed, measured, and weighed and the density of each block determined. This was approximately 6 pounds per cubic foot, Two methods were used for sawing the paper honeycomb: one, a band saw with four teeth per inch running at a speed of 4,000 feet per minute (fig. 10); and two, a circular saw with 4-1/2 teeth per inch turning at 1,770 revolutions per minute (fig. 11). Both methods were used depending upon the availability of the saws.

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[5]Development of this paper honeycomb core material was made in cooperation with the National Advisory Committee for Aeronautics.

[6]Appendix III Note 19.

[7]Appendix III Note 2.

Paper honeycomb cores of 1/8- to 3/4-inch thickness (along the cells) were required for various test panels. When cut to a thickness of 1/8 inch, the outer cells of the paper honeycomb with a density of 6.5 pounds per cubic foot were often broken, but this breakage did not develop when higher density material (8 pounds per cubic foot or greater) was used (figs. 12 and 13). None of the paper honeycomb of higher density (8 to 12 pounds per cubic foot) could be sawed successfully to a thickness less than 1/8 inch, but all the paper honeycomb with a density of 6 to 12 pounds per cubic foot was sawed satisfactorily to a thickness of 3/16 inch (figs. 14 and 15). Later it was found that by reducing the resin content of the outside corrugations, the 6.5-pound material could be cut to 1/8-inch thickness, As the blocks were sawed, a constant check was made on the variation of the thickness, which was held to a tolerance of ±0.005 inch. In order to keep the variation to a minimum, it was found necessary to lay up the blocks of core material on a flat surface. At one time a slight curvature developed along the 12-inch dimension of the blocks and produced a slight taper on each piece as it was cut that exceeded the allowable tolerance. This was remedied by using a heavy piece of plywood, about 1 inch thick, in the core jig as a laying-up platform for the cores,

After the pieces were cut and checked for thickness, they were glued together with a phenolic-resin (adhesive N)[8], on the high-frequency edge-gluing machine. The corrugations of one piece were nested into the corrugations of the other so that a strong glue bond would be obtained and thus make the finished core easier to handle. Where cores were required that were longer than 38 inches, which was the approximate length of the trimmed block, another piece from the same block was butted end to end and glued in the same manner by meshing the corrugations. After assembling, the cores were sanded with fine sandpaper on a wood block to remove glue squeeze-out and other minor surface imperfections. Figure 16 shows a typical piece of paper honeycomb core. No attempts were made to make matched cores, since the density variation in any one block was often as great as, the density variation between different blocks.

Glass-cloth Honeycomb[9]

The glass-cloth honeycomb was received from the manufacturer in blocks 3-1/2 by 17 by 18 inches with a cell size of 3/16 inch in the 17-inch direction. The density varied from 7 to 10 pounds per cubic foot. In making glass-cloth honeycomb about 60 percent resin by weight. was used. The resin content was determined by heating small samples to 1,000° F. for about one-haif hour, or to constant weight, in an electric furnace.

From several cutting trials the best method found to cut glass-cloth honeycomb into thin sections with the equipment available was to use a 14- or 24-tooth metal-cutting band saw mounted on the wheels so that the teeth

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[8] Appendix III Note 14.

[9] Appendix III Note 25.

traveled backwards at a speed of 3,500 feet per minute (fig. 17). Other saws with larger teeth or teeth running in the forward, or normal, direction caused considerable breakage. The normal thickness used was one-half inch and was not difficult to saw, but considerable difficulty developed with thicknesses under three-eighths inch because the honeycomb material fell apart (fig. 18). All sections were measured and held within the tolerances of ±0.005 inch of the desired thickness. The fuzzy character of the surface produced by the saw is shown in figure 19.

Originally the glass-cloth honeycomb was sawed with a band saw by use of a solid wood fence, which produced a fins suspension of resin dust in the atmosphere and resulted in skin irritations and other effects on the operator. This difficulty was overcome by drilling holes in the wood fence near the saw and applying a suction on the far side to draw off the dust (fig. 17).

The cut sections were glued together with a phenolic-resin (adhesive N), in the high-frequency edge-gluing machine by nesting the corrugations of the adjoining pieces. Cores made of glass-cloth honeycomb required more delicate handling than paper honeycomb cores, probably because of the shorter pieces used and the nature of the material. The cores were sanded to remove glue squeeze-out and obtain a uniform surface.

Gotton-cloth Honeycomb[10]

The cotton-cloth honeycomb material was received from the manufacturer in blocks about 8 by 9 by 125 inches with the 7/16-inch hexagon cells running in the 9-inch direction. Since most of the material was to be made into panels 1/2 by 36 by 36 inches, the blocks were cut into 38-inch lengths. These individual blocks were measured and weighed and found to have a density of about 3.65 pounds per cubic foot. Due to the lack of availability of the 4-ounce cotton duck, another cotton cloth of similar quality was used by the manufacturer in some of the blocks, which reduced the density to approximately 3.25 pounds per cubic foot. The cotton-cloth honeycomb was cut into thin sections of 1/2-inch thickness with a 4-tooth band saw running at 3,500 feet per minute (fig. 20). Because of the thickness of the blocks and the flexibility of this type of structure a great deal of material was wasted in cutting, with the greater percentage of rejections occurring toward the end of the block. A tolerance of ±0.005 inch was permitted in the thickness of the cut sections. The nature of the surface formed by the band saw Is shown in figure 21.

Due to the hexagonal shape of the cells and large area for contact, the sections of cotton-cloth honeycomb were glued together node to node with a phenolic-resin (adhesive N), using the high-frequency edge-gluing machine. The cores were sanded to remove excess squeeze-out of the adhesive N and other nonuniformi ties.

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[10] Appendix III Note 26.

Preparation of Face Material

Plywood

All of the plywood faces were 0.070-inch, three-ply birch manufactured in accordance with Specification AN-NN-P-511b. The glue used was a high-temperature-setting, phenolic dry film glue (adhesive U).[11] No special treatment was given the plywood other than to condition it for approximately 1 week at 65 percent relative humidity at 80° F.

Aluminum

The aluminum used was described as follows:

Thickness Inch	Type	Sheet Size
0.005	24SH	20 by 42 inches
.012	24ST Alclad	2 by 10 feet
.020	24ST Alclad	3 by 12 feet
.032	24ST Alclad	3 by 12 feet

The identification marks were first removed by washing with acetone. This was followed by cleaning and etching in a sulfuric acid-sodium dichromate bath (10 parts by weight of concentrated sulfuric acid, 1 part of sodium dichromate, and 30 parts of water) for 20 minutes at 145° F. or 8 to 10 minutes at 160° F. The sheets were rinsed and if a smooth unbroken water film was not obtained, the sheets were returned to the etching solution until an unbroken water film was obtained.

Glass-cloth Faces

Heat treated glass cloth[12] in combination with various laminating resins was used for all glass cloth faces until July 1946. Since that date glass cloth that was heat cleaned and treated with a chrome complex compound[13] was used. Characteristics of the cloth as received were as follows:

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[11] Appendix III Note 20.

[12] Appendix III Note 23.

[13] Appendix III Note 24.

Roll size - 38-3/4 inches wide
Thickness - 0.003 inch
Weight - 2.09 ounces per square yard (without selvage)
Type of weave - plain
Minimum breaking strength - Warp - 100 pounds per inch
Fill - 70 pounds per inch.

Since all glass-cloth faces were cross laminated, the cloth was first cut to size. Cuts were made following a pulled thread to assure edges parallel to the threads.

In early work, the laminating resin was applied to the cloth by hand as shown in figures 22 A and B. A film of the resin was produced on a large stainless steel plate by slowly squeegeeing the resin to a uniform thickness while the plate was slightly warmed by radiant heat. The cloth sheets were then laid on the resin film and gently worked down with a dry squeegee. After a short wicking period the sheet was removed and weighed for resin pick-up. The average resin content of the impregnated sheets was 43 to 45 percent of the total weight of cloth and resin. The sheets were rolled on cellophane-covered steel pipes and stored at 40° F. until ready for use. This storage period of 1 day to several weeks permitted the resin to wick uniformly through the entire roll.

The foregoing method was satisfactory for making a few panels, but required too much time when a greater number were needed. Therefore, a mechanical spreader was used for high-viscosity laminating resins (A and C), a6 shown in figure 23. Here the cloth passed around an idler roller in contact with a driven roller, was continuously coated by means of a doctor blade with a film of the laminating resin, and was then rolled up on a paper or copper tube covered with cellophane. The resin content varied between 45 and 75 percent depending upon the temperature and thickness of the resin fila on the roller. The roll of impregnated cloth was wrapped in cellophane and stored at room temperature overnight or at 40° F. for a longer period to permit the resin to wick uniformly through the entire roll. The cloth was then cut into the desired size and weighed to determine the resin content. Usually the resin content was over the desired 45 percent and therefore dry sheets were cut and placed between the wet or impregnated sheets to produce the desired resin content in the assembled material. The number of dry sheets used depended upon tho resin content of the wet sheets. After laminating the wet and dry sheets, they were rolled tightly on a pipe, and stored at room temperature overnight to allow the resin to penetrate the dry shoots, after which they were ready for laying up into a panel.

For low-viscosity laminating resins (B and D), the procedure was simpler and more easily controlled. Here the mechanical spreader was used only as a means of rewinding the glass cloth (fig. 24), and the resin was poured on as the cloth was rolled up. The resin content varied between 45 and 50 percent of the total wet uncured weight. The roll of impregnated cloth was immediately wrapped in cellophane to prevent the loss of volatile components of the resins and then stored in a room at 40° F. until used. Because the spread of the low-viscosity resin could be controlled accurately, it was not necessary to interleave the impregnated glass cloth with dry sheets.

Panel assembly Techniques

Plywood to Balsa,

Panels with end-grain balsa cores and plywood faces were glued with a high temperature-setting melamine resin, (adhesive R).[14] 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 to 7 days the panels were assembled and bag-molded on a flat aluminum mold or pressed in a hot press. The curing cycle was 15 minutes at 50 pounds per square inch pressure and 300° F. Panels were removed hot and no trouble was experienced with blistering due to internal pressure.

Aluminum to Balsa

Method 1.--The work plan originally specified a primary and secondary bonding process, therefore all aluminum faces that were later to be glued were sprayed with a high-temperature-setting, modified thermoplastic resin, (adhesive H).[15] 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. A light sanding with a fine emery cloth prepared the surface of the cured film for the secondary gluing. These primed aluminum faces were bonded to the balsa cores with a room-temperature-setting, resorcinol resin (adhesive P)[16] for the durability and the first few strength-test panels. A spread of 35 grams of adhesive P per square foot was brushed on the treated aluminum faces and the panels were pressed at room temperature at 50 pounds per square inch pressure for a minimum of 4 hours, either in a bag or in a hydraulic press,

The use of a wet glue under metal faces obviously trapped considerable liquid, which eventually was absorbed by the cores. In thin panels (1/8 to 1/4 inch thick) this trapped liquid raised the moisture content of the core to objectionable values for strength-test specimens. For example, if the solvent in adhesive P were assumed to be all water (it is actually part alcohol) the moisture content of the balsa core in a 1/8-inch aluminum-balsa sandwich would be raised from 6 to about 50 percent in gluing. The moisture could not escape except through the edges, therefore the moisture content remained excessively high for a period of months.

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[14] Appendix III Note 17.

[15] Appendix III Note 8.

[16] Appendix III Note 15

Method 2.--To eliminate this condition, preliminary tests were made on possible "dry-gluing" techniques for bonding aluminum faces, that had been coated with adhesive H, to end-grain balsa. A high-temperature-setting, thermoplastic vinyl resin (adhesive Q),[17] was found to give acceptable bonds and, therefore, was used on some of the strength-test panels. After thinning with alcohol, it was applied by brushing to the primed aluminum faces until a dry spread of 10 grams per square foot was obtained. This required 8 to 10 coats with a few minutes of air drying after each coat. The final coat was allowed to dry at least 24 hours to eliminate most of the solvent. On cores thicker than one-eighth inch, one-half of this quantity was applied to the core and the other half to the face. Adhesive Q swells wood to such an extent that applying it to 1/8-inch cores produced damaging wrinkles. The cores and faces were then assembled and the panels were cured for 30 minutes at 275° F. and 75 pounds per square inch pressure in a bag, or 100 pounds per square inch in a press, and cooled under pressure. Due to the limited flow of the adhesive Q and the inaccuracies of the balsa core, a cushion of soft synthetic rubber about one-eighth inch thick or its equivalent was required on both sides of the panel when it was pressed between platens.

Thin aluminum-balsa panels of suitable flatness were difficult to produce. The hydraulic press used had individual temperature controls for each platen, and a temperature differential of as little as 3° F. between the two platens, in either the heating or cooling cycle, produced curved panels. Thin bag-molded panels molded on a flat mold were always slightly curved due to the nonuniformity of heating between the mold and the bag side.

Panels with 0.005-inch aluminum faces required a special treatment to avoid thermal-expansion wrinkles in the faces. The rubber cushion cauls were first preheated before inserting the panel to be pressed. The short period during which the panels were between these hot cauls while the press was closing expanded the aluminum faces before pressure was applied and eliminated the face wrinkles that were produced if no preheating was used.

Shortly after initiating this bonding procedure the manufacture of this glue was discontinued and a similar glue, (adhesive Q-1)[18], having a solvent claimed by the manufacturer to produce less wood swelling, was substituted. At the same time a new shipment of adhesive H, which appeared to have slightly different color characteristics after curing, was received. Panels pressed with these new materials blistered badly in curing, and it was necessary to raise the pressure to 100 pounds per square inch throughout the heating and cooling cycle in bag molding. One hundred and fifty pounds per square inch pressure was tried on the flat panels, but an exceptionally wavy surface indicating compression of the softer growth rings resulted. To correct this, a thicker rubber cushion was used at a pressure of 100 pounds per square inch.

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[17] Appendix III Note 16.

[18] Appendix III Note 16.

Because of the slight thermoplasticity of adhesive Q-1 it was possible to repress panels having blisters if the blisters were pricked to release the entrapped gas that appeared to develop when the air-dried adhesive Q-1 was heated.

So much difficulty with blistered faces was encountered with the adhesive H plus adhesive Q-1 gluing technique that improved bonding procedures were sought.

Method 3.--One of these involved the use of a high-temperature setting, modified thermoplastic resin (adhesive F)[19] directly on the etched aluminum surface. A dry spread of 12 grams per square foot was applied by brushing the cement, thinned with a mixture of ethyl acetate and ethyl alcohol, on the aluminum. About four coats were required with a half-hour drying period after each. The final coat was air dried about 24 hours before pressing. Panels were pressed between preheated rubber cushion cauls, or bag molded, at 2750 F. and a pressure of 100 or 75 pounds per square inch pressure respectively for 40 minutes and removed hot. No blisters resulted but, due to the light spread or to the nonflowing characteristics of adhesive F, the cushions were necessary on the aluminum-balsa, panels made in a press (fig. 25). This produced slightly wavy surfaces conforming to the irregularities of the core. The strength of the bond6 was probably sufficient for buckling- and shear-test panels, although from stripping tests it did not appear to be so great as that of the joints bonded with adhesive H.

Method 4.--The fourth method was similar to the third, with a high-temperature-setting liquid resin and thermoplastic powder (adhesive G)[20]-used in place of the adhesive F. The thermosetting liquid resin was brushed on the etched aluminum 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. These faces were pressed to the balsa cores between stainless-steel cauls in a press at 275° F. and a pressure of 100 pounds per square inch for 30 minutes and removed while hot. No blisters were encountered on the first few panels and the bonds seemed to be exceptionally good (fig. 26). Later, after some blistering was encountered, three sheets Of 0.020 inch paper on each side were used as cushions for panels cured in a press, Some panels were also bag molded in an autoclave at 275° F. and a pressure of 75 pounds per square inch for 1 hour. The panels were laid on a 1/4-inch aluminum mold, and a 1/8-inch rubber pad was laid over the top face.

Method 5.--An additional bonding method was used that incorporated a high-temperature-setting, modified thermosetting priming resin (adhesive M)[21] applied in six spray coats directly to the etched aluminum, air dried overnight, and cured in an oven at 325° F. for 30 minutes. After sanding, the faces were bonded to the balsa core with a high-temperature-setting phenolic resin (adhesive N)[22], in a press or bag at 230° F. and a pressure of 75 pounds per square inch for 1 hour, Some panels were made by applying a light spray coat of adhesive S[23] to the balsa to reduce to the rapid absorption of adhesive N during curing.

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[19] Appendix III Note 6.

[20] Appendix III Note 7.

[21] Appendix III Note 13.

[22] Appendix III Note 14.

[23] Appendix III Note 18.

Glass Cloth to Balsa and Glass Cloth to Cellulose Acetate

Panels with glass cloth faces and balsa cores were assembled and cured in one operation with no additional resin between the faces and the core. This is commonly known as "wet laminating."

The normal procedure was to cover the flat caul or curved metal form with a parting film of cellophane. The choice of cellophane proved important as some types of film bonded to the resin, such as the self-sealing and moisture resistant types. The impregnated glass cloth for one face was then laid, one sheet at a time and cross laminated, on a flat caul or curved mold. This procedure was repeated for the other face on the matching flat caul or, (for a curved mold) on a piece of cellophane taped to a flat surface. The balsa core was then laid on one of the faces, and covered with the Lay-up for the opposite face. This procedure was preferred to the method of laying the glass cloth directly on the core.

Due to slight waviness of the balsa core surfaces, as described previously, fluid pressure or its equivalent was necessary to assure intimate contact between the glass cloth and the core. Large flat panels 1/8-inch thick required for some of the test panels were difficult to bag mold to acceptable flatness due to nonuniform heat penetration. These panels could, however, bo made in a press if suitably cushioned cauls, to simulate fluid pressure, were used on each side. Rubber was tried for these cauls but was unsuitable for two reasons: first, the rubber available that would withstand the high temperature was too hard; and second, materials contained in or formed when this rubber was heated were likely to inhibit the cure of the resin, even when covered with cellophane.

After experimenting with other cushioning materials for pressing, such as cloth and blotting paper, a soft-textured wool blanket was found to produce the desired results. Four. and one-quarter-pound wool bed blankets 72 by 84 inches were cut to the desired caul size and laid on 5/16-inch poplar plywood. The blanket surface was covered with heavy kraft paper and finally with cellophane. These composite cauls provided the equivalent of fluid pressure and at the same time slowed the heating of the panel to approximately that obtained by vacuum bag molding in hot air. For bag molding, a 0,020-inch aluminum caul covered with cellophane on one side was used.

The following five assembly methods were used to fabricate the glass cloth-to-balsa panels and the first four for the glass cloth-to-cellulose acetate panels:

Method 1.--Both flat and curved panels were fabricated with a high-viscosity laminating resin (A)[24] and cured in a bag or press at 225° F. and a pressure of 13 pounds per square inch for 1-1/2 hours. During this curing

[24]Appendix III Note 1.

cycle resin A apparently became fairly liquid before it hardened. In this liquid state it was absorbed somewhat by the end-grain balsa in quantities inversely proportional to the density of the balsa. The variations in absorptions probably accounted for the somewhat spotty appearance of panels with faces of only three plies of cloth (fig. 27). A check of average resin loss from the faces showed that three-ply glass cloth faces originally containing 43 percent resin dropped to 36 percent upon stripping from the balsa cores after pressing.

Panels of these combinations were made with core thicknesses of one-eighth, three-sixteenths, one-fourth, seven-sixteenths, one-half, three-fourths, and 1 inch, and faces of 2, 3, 4, 6, 8, and 10 plies of glass cloth. Acceptable panels could be made by the normal process in all combinations except the curved panels with ten-ply faces. In these thick faces, blisters between the plies, and between the faces and the core persisted in spite of the omission of the aluminum caul and pinpricking of the assembly at 3-inch intervals in an attempt to bleed the air. A replacement set of panels molded by the same technique but at 40 pounds per square inch pressure had no blisters and was acceptable. It is doubtful, in the light of this experience, if vacuum pressure is sufficient to insure blister-free sandwich panels with thick glass-cloth faces.

Method 2.--After the glass cloth was treated with resin B,[25] a low-viscosity laminating resin (see "Preparation of Face Materials"), the glass cloth was rolled tightly in cellophane to prevent the loss of the styrene and the drying of the resin. Because of this evaporation and drying effect, the treated glass cloth had to be cut to size, weighed for resin content, and laid on the caul or mold within 2 or 3 hours. If the spread sheets were exposed to the air for a longer period, the glass cloth became so dry that the wrinkles (produced in laying up the sheets) were difficult to remove due to the lack of slippage between the sheets. Glass cloth treated with resin B can be kept for several day6 if wrapped tightly in cellophane and stored at temperatures below 40° F. Another method that was used to reduce the exposure time of the individual sheets to the air was to weigh the mold and caul, lay the sheets on the mold or caul as soon as they were cut, and then weigh the mold or caul with the assembled face for determining the resin content.

The panels were bag molded in a steam-heated oven or pressed between cellophane-covered blanket cauls at 250° F. and a pressure of 13 pounds per square inch for 1-1/2 hours.

Method 3.--The details for assembling panels using resin C,[26] a high-viscosity laminating resin, were similar to those used for resin A. The panels were cured at 240° F. and a pressure of 13 pounds per square inch for 1-1/2 hours .

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[25] Appendix III Note 2.

[26] Appendix III Note 3.

Method 4.--The details for assembling panels using resin D,[27] a low-viscosity laminating resin, were similar to those used for resin B, except that the curing temperature used was 220° F.

Method 5.--Panels with resin E,[28] a low-viscosity laminating resin, were made only with balsa cores. The glass cloth was impregnated by the hand method, but could also be done by the method used for the other low-viscosity resins. These panels were Bag molded in a steam-heated oven or pressed between cellophane-covered blanket cauls at 275° F. and a pressure of 13 pounds per square inch for 4 hours,

Plywood to Cellulose Acetate and Plywood to Cellular Hard Rubber

Panels of plywood bonded to cellulose acetate and of plywood bonded to cellular hard rubber were made by brushing a room-temperature-setting, resorcinol resin (adhesive P) on the plywood faces only and pressing the panels in a vacuum bag or press at a pressure of 13 pounds per square inch at room temperature for a minimum of 4 hours.

Aluminum to Cellulose Acetate

The following five methods were used for durability and strength-test panels made of aluminum bonded to cellulose acetate.

Method 1.--The primary-secondary gluing method of using adhesives H and P, as discussed under aluminum-to-balsa method 1, was used for this combination, except that the pressure was reduced to 13 pounds per square inch.

Method 2.--Gluing method 2 used for aluminum-to-balsa panels was applied to this combination, except a pressure of 40 pounds per square inch was used in molding the panels. With this adhesive, it was necessary to cool the panels under pressure.

Method 3.--A high-temperature-setting, modified thermoplastic resin (adhesive F) thinned with a mixture of ethyl alcohol and ethyl acetate was brushed on the etched aluminum to a dry spread of 14 grams per square foot. About four coats were required with a half-hour drying period after each coat and 24 hours after the final coat. Panels were pressed with three sheets of heavy kraft paper on each face or bag molded at 275° F. and a pressure of 40 pounds per square inch for 40 minutes and removed hot.

Method 4.--The etched aluminum was sprayed with 6 coats of a high-temperature-setting, modified thermosetting priming resin (adhesive M) allowing 1/2-hour drying between each coat and a 24-hour drying period after the final coat. The primed aluminum faces were cured in an oven at 325° F.

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[27] Appendix III Note 4.

[28] Appendix III Note 5.

for 30 minutes, cooled and sanded with fine sandpaper to remove irregularities of the surface. The faces were spread with a room-temperature-setting, resorcinol resin (adhesive P) to a weight of 35 grams per square foot. The panels were pressed or bag molded at 13 pounds per square inch for a minimum of 4 hours.

Method 5.--The same method used for aluminum to balsa (method 5) was applied to this combination, except the molding pressure was reduced to 40 pounds per square inch. The spread of the secondary phenolic resin (adhesive N) used on the aluminum faces was 10 grams per square foot.

Aluminum to Cellular Hard Rubber

Panels of aluminum to cellular hard rubber were made by the following two gluing methods:

Method 1.--Panels were made by the same procedure as gluing method 1 under aluminum to balsa, except that a reduced pressure of 13 pounds per square inch was used.

Method 2.--Panels were made by the same procedure as gluing method 4 under aluminum to cellulose acetate. The entrapped moisture encountered with the secondary adhesive used for both these methods caused no apparent difficulty.

Class Cloth to Cellular Hard Rubber

Since rubber inhibited the cure of all the laminating resins used in this study when the two were in intimate contact during the curing cycle, the normal wet-laminating process as used on balsa and cellulose-acetate cores could not be employed. If, however, a suspension (about 15 percent concentration) of the catalyst (benzoyl peroxide) in water was sprayed or brushed on the rubber core and allowed to dry, the normal laminating process could be used with fair results, although difficulties were encountered with these panels. One such example is shown in figure 28. In the first trials of this method, an acetone solution of benzoyl peroxide was applied to the faces, but tension tests perpendicular to the face on panels made by this method gave values below those expected for rubber. It was thought that the acetone might be weakening the surface layer of the rubber. When water was substituted for the acetone the tension values were raised. The catalyst is not soluble in water and must be applied as a suspension prepared by adding a small amount of ethyl alcohol (5.0 percent) to the water before adding the benzoyl peroxide. The material must be stirred or agitated during application to keep it in suspension.

Cores before and after application of the catalyst are shown in figure 29. Panels were made by wet laminating glass cloth faces impregnated with resin A on the treated cores by the same method as that used on the glass cloth-to-balsa combination.

Plywood to Paper Honeycomb; Plywood to Glass-cloth Honeycomb; Plywood to Cotton-cloth Honeycomb

Panels with plywood faces and paper honeycomb or glass-cloth honeycomb cores were glued with a high-temperature-setting phenolic resin (adhesive N). A wet spread of 20 grams per square foot was applied to the faces and 5 grams per square foot to the core. The adhesive was spread on the faces and core with a roller, and then allowed to dry from 1 to 24 hours before assembling. The panels were assembled on an aluminum mold with a pine frame around the panel to prevent crushing of the edges, and bag molded in an autoclave at 2300 F. and a pressure of 30 pounds per square inch for 1 hour.

The same techniques used to fabricate the plywood to paper honeycomb combination were used for plywood to cotton-cloth honeycomb, except the molding pressure was reduced to 13 pounds per square inch.

Aluminum to Paper Honeycomb

Five adhesives were suggested and approved for gluing aluminum faces to paper honeycomb cores. The methods of preparing panels with these adhesives were as follows:

Method 1.--The procedure used for preparing the aluminum faces and spreading the adhesive G, a thermosetting liquid resin and a thermoplastic powder, was the same as used in the aluminum-to-balsa combination, except that a wet spread of 35 grams per square foot of the resin instead of 20 grams per square foot was used. This additional fila thickness appeared necessary to obtain better adherence to the core. In addition, the core was coated only with the thermosetting liquid of adhesive G by a rubber roller to a spread of 10 grams per square foot on each side. After drying for 24 hours, these panels were molded on a 1/4-inch aluminum mold, with a wood frame around the edges of the panel, and the top face of the panel was covered with a 1/8-inch rubber pad. The rubber pad was used to reduce the conduction of heat to the top face and make it comparable to the heat reduction caused by the mold. The panels were cured in an autoclave at 275° F. and a pressure of 30 pounds per square inch for 1 hour.

Method 2.--The method of applying adhesive F, a thermoplastic rosin, to the aluminum faces was the same as used for the aluminum-to-balsa combination. The core was given two roller coats of adhesive F, with a half-hour period between coats to allow the solvent to escape, which gave a spread of approximately 2 grama per square foot, The assembly for bag molding consisted of an aluminum mold, a wood frame around the edges of the panel, and 1/8-inch rubber pad over the top face. The panels were cured in an autoclave at 275° F. and a pressure of 30 pounds per square inch for 1 hour.

Method 3.--Adhesive L,[29] a thermosetting resin and synthetic rubber, was applied directly to the etched aluminum by brush to an air dry spread of 15 grams per square foot. The adhesive L, as received, was thinned with acetone from 30 to 50 percent by volume. About four coats were required to obtain the required glue film, allowing at Least one-half hour between coats and 24 hours' drying after the last coat. Adhesive L was applied to the paper honeycomb core with a hard rubber roller until a dry spread of 5 grams per square foot was reached. These flat panels were bag molded in an autoclave at 2600 F. and a pressure of 30 pounds per square inch for 1 hour. Like the previous panels, a wood frame was used around the edges to prevent crushing and a 1/8-inch rubber pad was laid over the top face to prevent a curvature in the panel after molding.

Method 4.--Adhesive J,[30] a thermoplastic and thermosetting resin also may be applied directly to aluminum when properly prepared, as etching in a hot sulphuric acid and sodium dichromate bath. For brush application, this adhesive was thinned with a special thinner to 30 percent by volume. About four brush coats were required to build up a dry film thickness of 0.006 to 0.010 inch, or about 20 grams per square foot on the aluminum faces. One hour or longer of drying was allowed between each coat, and 24 hours after the final coat. A dry spread of 10 grams per square foot was applied to the core with a rubber roller. The panels were assembled for bag molding and cured in an autoclave at 275° F. and a pressure of 30 pounds per square inch for 1-3/4 hours. The precure and cure that were recommended for adhesive J were carried out in one operation under closed assembly. The panels were removed hot and no blisters were apparent.

Method 5.--The primary adhesive M, which was a primary high-temperature-setting, modified, thermosetting resin, was sprayed on the etched aluminum sheets in six coats to an approximate 0.003-inch film thickness. After drying overnight the sprayed sheets were cured in a press at 320° F. for 30 minutes. Prior to applying the secondary adhesive N, which was a secondary high-temperature-setting, phenolic resin, the cured primary adhesive M was sanded lightly and wiped with a clean cloth and methyl alcohol. A wet spread of 20 grams per square foot of the secondary adhesive N, was applied with a rubber roller and dried for 1 to 24 hours before assembling. The paper honeycomb core was coated with a wet spread of 5 grams per square foot on each side by a roller and dried for the same period. The panels were then assembled and bag molded or pressed at 230° F. at a pressure of 30 pounds per square inch for 1 hour. For bag molding, the panel was laid on an aluminum mold with a wood frame around the edges, and a 1/8-inch rubber pad was placed over the top face. For pressing, three sheets of heavy paper were used as cauls to conform to the irregularities due to the cutting and fabricating of the paper honeycomb cores. The panels were removed while hot.

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[29] Appendix III Note 12.

[30] Appendix III Note 10.

Aluminum to Glass-cloth Honeycomb

The five adhesives that were discussed under aluminum to paper honeycomb combinations were also used for aluminum to glass-cloth honeycomb. Since the glass-cloth honeycomb has essentially the same structure and sufficient compressive strength to withstand the fabrication pressures at elevated temperature used on paper honeycomb, the same spreads and conditions used for the various adhesives under aluminum to paper honeycomb were used for glass-cloth honeycomb.

Aluminum to Cotton-cloth Honeycomb

The same five adhesives used for aluminum to paper honeycomb panels were used to make aluminum to cotton-cloth honeycomb panels. The conditions of fabricating the panels were also the sane, except that the pressures were reduced to 20 pounds per square inch for pressing operations and about 15 pounds per square inch for bag molding in an autoclave or steam-heated oven. The pressures and equipment used for curing the cotton-cloth honeycomb panels are summarized as follows:

Method 1.--When adhesive G was used the panels were cured in a press at a pressure of 20 pounds per square inch.

Method 2.--When adhesive F was used the panels were cured at a pressure of 13 pounds per square inch in a steam-heated oven.

Method 3.--When adhesive L was used the panels were cured at a pressure of 18 pounds per square inch in an autoclave.

Method 4.--When adhesive J was used the panels were cured in a press at a pressure of 20 pounds per square inch.

Method 5.--When adhesives M and N were used the panels were cured at a pressure of 15 pounds per square inch in an autoclave.

Glass Cloth to Paper Honeycomb; Glass Cloth to Glass-cloth Honeycomb; and Glass Cloth to Cotton-cloth Honeycomb

Five contact-pressure laminating resins were included in the working plan for impregnating glass cloth as faces for panels with the various honeycomb cores. The manufacturer could not supply the low-viscosity laminating resin (E) within a reasonable time and therefore it was not used in combination with the honeycomb cores. The methods of preparing the panels with the four laminating resins are discussed as follows:

Method 1.--The impregnating of the glass cloth for the faces with the high-viscosity laminating resin is presented under "Preparation of Face Materials -- Glass cloth faces," and the procedure used to fabricate the panels followed the same steps as used for the glass cloth-to-balsa combination. At first no resin was put on the core material, but from strength tests, (table 1) it was found that such an application greatly improved the bond. A spread of 10 grams per square foot was therefore applied to each side of the paper honeycomb and glass-cloth honeycomb cores and 5 grams per square foot to each aide of the cotton-cloth honeycomb cores. The impregnated cloth was used for several weeks after it was treated with resin A. Panels were assembled on an aluminum mold, covered with cellophane and bag molded in a steam-heated oven at 225° F. and vacuum pressure for 1 hour. Other panels were made in a press at 225° F. and a pressure of 15 pounds per square inch for 1 hour with blanket cauls.

Method 2.--The impregnated glass cloth faces made with the low-viscosity laminating resin B were prepared in the same manner as for glass cloth-to-balsa panels made with resin B. Since increased strength was obtained by applying resin to the cares, the paper honeycomb and glass-cloth honeycomb cores were coated with 10 grams per square foot of resin B with a roller, and the cotton honeycomb cores with 5 grams per square foot. For bag molding, the panel was assembled on a cellophane-covered aluminum mold, and a cellophane-covered, 0.020-inch, aluminum caul was used over the top face. These panels were bag molded in a steam-heated oven at 250° F. and vacuum pressure for 1 hour. When pressed, the panels were cured at 250° F. and a pressure of 15 pounds per square inch for 1 hour with blanket-cushioned cauls as described previously.

Method 3.--The methods used for resin C, a high-viscosity laminating resin, were similar to those used for resin A of glass cloth-balsa, except that the curing temperature was 240° F. instead of 225° F. The three honeycomb core materials were also coated with resin C with a roller as discussed previously.

Method 4.--The techniques used to fabricate glass cloth panels with resin D, a low-viscosity laminating resin, were the same as those used for resin B, except that the curing temperature was 220° F.

Curved Sandwich Panels

A few tests were made to determine the limits of curvature of various core materials and few sandwich constructions. These bending tests and fabrication trials were limited to single curvature.

Panels with only slight single curvature could readily be molded by merely draping the core and faces over a convex mold or laying them in a concave mold and later inserting the whale assembly in a bag after temporarily taping the pieces to the mold. An assembly of this kind on the convex side of a steel mold is shown in a bag in figure 30.

As the curvature became more severe, it became more difficult to bend the core to shape and to draw it down firmly to the mold surface. The anticlastic (saddle-shaped) curvature, which the core materials tend to assume upon bending, caused some difficulty even at moderate curvatures. This phenomenon was particularly noticeable with honeycomb cores. The limitations imposed on curvatures of core materials by their tendency to assume an antielastic curvature has not been fully investigated in this study, but panels having 1/4-inch thick paper honeycomb cores have been molded to a 30-inch radius with no difficulty.

Often the severity of curvature to which a panel can be molded by the "draping method," or one-step molding process, is limited by breakage of the core material. An attempt to evaluate this limitation was made by determining the approximate breaking radius of 1-inch wide strips of four core materials in a variety of thicknesses from 1/8 to 1/2 inch. The results of these tests are presented in figure 31. The four lower lines represent the average approximate breaking radii and therefore cannot be used directly in estimating the minimum working radii. If a factor of safety against breakage of about 2 is applied to the radii, however, it is believed that reasonably safe working radii will be obtained. This factor has been investigated, in an exploratory manner, by bending larger sheets of core material between sheets of thin aluminum, and the upper line in figure 31 represents the results, which can be used in determining an approximate safe working radius for all four of the core materials tested in the form of strips.

If it is desired to make curved sandwich panels having radii smaller than the safe working radii presented in figure 31, other special means of forming the core must be employed. Some core materials, such as cellular cellulose acetate, cellular hard rubber, and paper honeycomb, lend thenselves fairly well to post-forming. Another method, which perhaps is less cumbersome is to glue or laminate one face to the core in the first operation, bend the assembly to approximately the proper shape, the faced side being the convex side, and glue the inner face to the core in a second molding operation to produce a sandwich panel of the desired shape. Figure 32 shows the bending operation being done in a conventional hand-operated sheet metal rolling machine. The panel being bent is end-grain balsa glued to an aluminum face.

The limits on minimum radius for this bending operation were again investigated on strips, and it was found that 1/2-inch thick strips of any of the four core materials with either an aluminum or a glass-cloth face on one side could be bent to a radius of lese than 2 inches without excessive damage.

After bending, the molding operation can be completed on either a male or female mold by use of fluid pressure. Both methods were used experimentally in this study to explore in a preliminary way the advantages of each. Several steps in the use of a male wood mold are shown in figure 33. The parts to be molded are first assembled on the mold and temporarily held in place (in this case by screws) (fig. 33A). Several layers of heavy canvas are wrapped around the mold (and appropriate projections from the mold) to provide adequate pressure at the point of severest curvature (fig. 33B). The assembly is then inserted in a bag and a vacuum drawn before molding in an autoclave (fig. 33C). After the part is molded and cooled its curvature is not exactly the same as that of the mold (fig. 33D). This difference in curvature between mold and product is e fundamental disadvantage of the use of a mold having considerable body, and is caused by nonuniform temperature conditions between inner and outer faces of the product at the time the glue sets.

After this curved piece was trimmed, as shown in figure 34, it was used as a female mold in molding a similar piece. Four steps in this molding operation are illustrated in figure 35. The parts, after being bent as before, were placed in the mold (fig. 35A). It was known to be exceedingly difficult to force the parts into a concave mold of this type. Therefore a device utilizing a fire hose backed up by a support. which in turn was restrained by a canvas around the mold, was used to force the parts into the region of severest curvature before a vacuum was drawn on the bag. This device is shown in figure 35B. After the vacuum was drawn the assembly appeared as shown in figure 35C. It was then molded by conventional methods in an autoclave. The untrimmed finished part is shown in figure 35D, and again the curvature of the part did not conform to tho curvature of the mold. The nonconformance was less than before due to the relatively thin mold.

In spite of the precautions taken to provide adequate pressure at the point of greatest curvature the molded piece had a poor bond, and actual gaps occurred between the inner face and the core at this point, again emphasizing the difficulty of molding parts of U shape.

APPENDIX I

Balsa Lumber Specifications

Specification used through June 1945:

Lumber, Balsa, S23, weight 6 to 9 pounds per cubic foot, kiln dried, random widths of 3 inches and up, and random lengths with a minimum length of 6 feet. Thickness shall be 1–1/2 inches or 2-1/2 inches with not less than 50 percent of the material of 2-1/2-inch thickness and not more than 50 percent of the material of 1–1/2–inch thickness with an allowable tolerance not more than 1/8-inch plus or minus.

Specification used after July 1945:

Balsa Lumber, rough, weight 5 to 8 pounds per cubic foot, kiln dried, 3–inch thickness, random widths, random lengths with a minim of material under 6 feet in length, to be graded in accordance with tho Foregin Economic Administration Grading Rules of March 1, 1944 for Grade AA.

Preliminary Experimental Work

Before adopting the manufacturing and fabricating techniques used on the test panels, many other methods were tried and discarded. Some of these, although not considered satisfactory, are worthy of discussion as a matter of record and as a guide in future work on sandwich manufacture.

Band Sawing End-grain Balsa

The band saw set-up shown in figure 8, which produced good results on cellulose acetate, was tried on balsa. The end-grain surfaces were fuzzy and were not suitable for gluing or wet laminating. If band sawing were followed by sanding on an accurate drum sander, the surface would probably be acceptable.

Planing End-grain Balsa

The surface produced on end-grain balsa by a high-speed, 30-inch cabinet planer is shown in figure 36. Although the knives were in very good condition, the fibers were not cut off square and clean and the surface was unsuitable for gluing.

Pressing End-gain Balsa

In an attempt to correct the wavy surface produced on balsa by its nonuniform density, sample cores were pressed between smooth surfaces at progressively higher pressures and temperatures to determine the crushing pressure at various temperatures. A pressure of 300 pounds per square inch at 300° F. for 1 minute produced flat cores with smooth surfaces by crushing the high (harder) rings and thicker slabs down to the thickness of the thinnest spots. This process was not used because of the possible physical changes in the slightly crushed balsa.

Spreading High-viscosity Laminating Resin (A) on Glass Cloth

The viscosity of laminating resin A is too high to make direct hand spreading practical for resin contents below 50 percent. An indirect method, such as shown in figure 22A and B must be used. For large-scale production, a mechanical coater should be used. One such type, a knife coater, is shown in figure 37.

Some serious defects were encountered when the resin content of the faces was too high. Figure 38 shows the results of high resin content in the faces combined with high pressure and temperature. The resin while in the liquid, heated state flowed into the slightly open edge-glued joints and into checks in the end-grain balsa core and actually compressed the balsa sideways or at right angles to the motion of the press. This panel had, approximately 55 percent resin content in the faces and was pressed in a press at 250° F. and 75 pounds per square inch pressure.

A single sheet of glass cloth with a resin content of 43 percent molded between cellophane sheets at 225° F. and vacuum pressure is shown greatly magnified in figure 39. Each square in the weave contains a small air bubble. Figure 40 shows a glass cloth face made of three cross-laminated sheets with 43 percent resin content and molded under the same conditions. The irregular pattern was caused by the register of the weave. 'If the squares registered exactly, large air bubbles were formed; if they meshed, practically no bubbles resulted, Thicker faces presented the same irregular pattern. It was particularly evident on the finished panel in reflected light.

Strength Determinations to Evaluate Fabrication Techniques

In order to evaluate the fabrication techniques and the glues to be used, preliminary panels, 1/4 by 12 by 12 inches, were made and tested by three methods -- tension, shear, and strip.

The Forest Products Laboratory tension specimens are made by bonding a 1-square-inch aluminum cube grip to each side of the sandwich. These specimens and testing apparatus are shown in figure 41. In conducting the test, a testing machine cross-head speed of 0.05 inch per minute was used.

The shear-test specimen used was similar to that employed as the standard for plywood shear tests, 1 by 3-1/4 inches, with a test area of 1 square inch. The ends of the specimens were gripped by modified jaws inserted in the standard machine for testing plywood in shear, Side plates were added to the standard type jaws so that support could be applied laterally to keep the specimen from twisting and bending under test. The load was applied at the rate of approximately 600 pounds per minute. Two shear-test specimens and the gripping jaws with the special side plate attachments are shown in figure 42.

The strip test was used to measure the energy required to strip the face from an area 1 by 3 inches from the center portion of a specimen 3 inches square. The aluminum or glass cloth face extended approximately 1 inch beyond the area to be stripped. Two saw cuts, 1 inch apart, were made through the metal face and about two-thirds through the core parallel to the sides, making a test area of 1 inch by 3 inches. The specimens were tested in the Forest Products Laboratory toughness testing machine with special gripping attachments. The force was applied at the 1-inch edge at an angle of 60° to the face. The initial angle of the pendulum was 45°, and from the angular position attained by the pendulum upon its release, a toughness value was obtained in inch-pounds. A tested specimen in the toughness testing machine is shown in figure 43, which also shows the method of attachment to the drum.

These tests were of a preliminary nature and were used only to indicate the best gluing and fabrication procedure to be used. Table 1 summarizes some of the results of the tests on panels with honeycomb cores and glass cloth, plywood, and aluminum faces.

One of the series of panels was made by using glass cloth faces (impregnated with five various laminating resins) and paper honeycomb and glass cloth honeycomb cores. The resin-impregnated glass cloth faces were "wet laminated" to the paper honeycomb and glass cloth honeycomb cores. The panels were then cut into tension, shear, and strip test specimens and tested as described previously, Additional panels, using the same combinations of face, cores, and resins, were made by the same conditions, except that extra resin was applied to the core. Ten grams per square foot, of the resin used to impregnate the face, was roller spread on the core before the panels were assembled and cured. The addition of resin to the core generally increased the strength of these panels when subjected to tension, shear, and strip tests. The results of these tests are summarized in table 1. Because the additional application of resin to the core increased the bond strength, it was used as standard procedure thereafter with all honeycomb core combinations.

Compression of Core Materials at Elevated Temperatures

Although the compressive strengths at room temperature of some of the core materials were known, the strengths that these materials would develop at molding and pressing temperatures (200° to 300° F.) were open to question.

Compression tests were conducted in a 14-inch steam-heated press, the pressure being controlled by a hand operated hydraulic pump. The temperature at the platen was controlled within ±2° F. of the desired reading. An asbestos fence was built around the platens to reduce the cooling effect on the outside edges of the test specimen.

The specimens were placed between aluminum cauls and put in the press, and the platens were brought together until they just touched the cauls. By keeping the specimens in this position for 15 minutes, the cores were brought up to the temperature of the platens before pressure was applied. Pressure was applied in increments of 10 pounds per square inch until a compression of 0.050 inch or more was observed, as shown by a dial indicator attached to the side of the platens. After the first load of 10 pounds per square inch was applied, the dial indicator was set on zero, and that pressure and each consecutive increase of 10 pounds per square inch was maintained for a period of 15 minutes. Readings of core compression were taken immediately after the pressure was applied and after the pressure was maintained for 15 minutes.

The results of these tests on the six core materials used for sandwich constructions are summarized in table 2. In general, the compressive strength of all the core materials was affected by temperature, decreasing as the temperature increased.

From the data obtained, cellular hard rubber was found to be the weakest material. This was also verified by the panels that were made with rubber as a core, since molding and pressing pressures could not exceed 15 pounds per square inch without considerable crushing. Balsa, on the other hand, was the strongest both at room and elevated temperatures, and the strength values far exceeded the capacity of the press (400 pounds per square inch).

Since the tests of compression strengths were determined by pressing, the values are more applicable to pressing than bag molding. In pressing, the load is not absorbed evenly over the entire area of the specimen, but is absorbed to a greater extent on the stronger areas and a lesser extent on the weaker areas, Therefore, the value obtained in pressing is an average of the entire area. In bag molding. where a fluid pressure is obtained, the load is distributed evenly over the entire area, and failure may occur in one area before it does in other areas. This was demonstrated by a panel made with aluminum faces and cotton honeycomb core, in which parts of the core were weaker as shown by a difference in color. When bag molded at 275° F. and a pressure of 30 pounds per square inch, crushing occurred only in the light-colored or weaker areas.

Table 1.--Results of tension, shear, and strip tests on panels having three honeycomb core materials

Sandwich construction			Bond strength					
			Tension		Shear		Strip	
Face	Core	Resin	Resin on face only	Resin on face and core	Resin on face only	Resin on face and core	Resin on face only	Resin on face and core
			P.s.i.	P.s.i.	P.s.i.	P.s.i.	Inch pounds	Inch pounds
Glass cloth	Paper honey-comb	A	242	405	165	175	3.1	4.3
		B	385	537	147	216	2.7	7.5
		C	365	390	234	201	5.0	11.3
		D	110	319	147	218	.73	2.7
Glass cloth	Glass cloth honey-comb	A	251	483	186	196	7.2	11.3
		B	472	537	351	253	6.8	7.6
		C	387	503	229	228	7.0	18.3
		D	255	430	259	304	10.0	9.5
Aluminum	Paper honey-comb	G	......	474	......	170	......	8.1
		F	......	285	......	118	......	6.7
		L	......	73	......	119	......	12.5
		J	......	491	......	139	......	3.6
		M & N	......	238	......	123	......	1.2
Aluminum	Glass cloth honey-comb	G	....	704	......	276	......	14.2
		F	......	174	......	181	......	12.0
		L	......	124	......	98	......	46.0
		J	......	267	......	156	......	6.4
Aluminum	Cotton cloth-honey-comb	J	......	171	......	......	......	......
Plywood	Glass cloth honey-comb	Q	......	52	......	77	......	1.0
		N	......	663	......	177	......	11.0
		L	......	99	......	125	......	17.5
		P	......	304	......	247	......	9.4
Plywood	Paper honey-comb	Q	......	81	......	79	......	4.5
		N	......	454	......	190	......	7.4
		L	......	102	......	113	......	9.6
		P	......	377	......	165	......	8.3

Table 2.--Compressive strength of six core materials as determined in a heated press on specimens 1/2 inch thick

Core material	Temperature	Density	Proportional limit	Load at 0.050-inch compression
	° F.	Lb. per cu. ft.	P.s.i.	P.s.i.
Balsa	300	6.19	More than 400	[1]400
Cellular cellulose acetate	Room	6.65	130	[2]220
	225	6.29	90	140
	250	6.20	90	130
	275	6.36	70	120
	300	....	70	120
Cellular hard rubber	Room	6.86	140	[2]160
	225	7.47	10	30
	250	8.13	10	20
	275	7.39	Less than 10	20
Paper honeycomb	Room	5.79	550	[3]550
	225	5.76	120	170
	250	....	110	160
	275	5.80	90	160
	300	5.71	90	140
Glass-cloth honeycomb	Room	8.18	390	420
	225	8.73	120	160
	250	8.50	90	150
	275	8.42	80	120
	300	8.88	70	110
Cotton-cloth honeycomb	Room	3.50	230	280
	225	3.86	120	[2]170
	250	3.61	100	140
	275	3.70	90	120
	300	3.77	80	120

[1]Load at 0.010-inch compression.

[2]Values were estimated from curves.

[3]Load at 0.027-inch compression.

Description of Resins and Adhesives

Note 1. Resin A. A high-temperature-setting, high-viscosity, contact-pressure, laminating resin of the polyester type.

Note 2. Resin B. A high-temperature-setting, low-viscosity, laminating resin of the styrene monomer, polyester type.

Note 3. Resin C. A high-temperature-setting, high-viscosity, contact-pressure, laminating resin of the polyester type.

Note 4. Resin D. A high-temperature-setting, low-viscosity, contact-pressure, laminating resin of the polyester type.

Note 5. Resin E. A high-temperature, low-viscosity, laminating varnish of the low-pressure type.

Note 6. Adhesive F. A high-temperature-setting, modified thermoplastic metal-to-wood glue.

Note 7. Adhesive G. A high-temperature-setting, two-component resin with a thermosetting liquid and thermoplastic powder.

Note 8. Adhesive H. A high-temperature-setting, thermoplastic resin with thermosetting resin and pigment.

Note 9. Adhesive I. High-temperature-setting mixture of thermoplastic resin and synthetic rubber.

Note 10. Adhesive J. A high-temperature-setting mixture of thermoplastic and thermosetting resins.

Note 11. Adhesive H. A high-temperature-setting mixture of thermoplastic resin and synthetic rubber.

Note 12. Adhesive L. A high-temperature-setting mixture of a thermosetting resin and synthetic rubber.

Note 13. Adhesive M. A high-temperature-setting mixture of thermosetting resin and synthetic rubber.

Note 14. Adhesive N. A high-temperature-setting, acid-catalyzed, phenolic resin.

Note 15. Adhesive P. A room temperature-setting resorcinol resin.

Note 16. Adhesives Q, and Q-1. A high-temperature—setting thermoplastic vinyl–resin adhesive.

Note 17. Adhesive R. A high–temperature–setting, melamine–resin adhesive.

Note 18, Adhesive S. A synthetic resin sizing.

Note 19. Adhesive T. A high–temperature–setting phenolic resin adhesive.

Note 20. Adhesive U. A high–temperature–setting, phenolic, dry-film glue.

Note 21. Cellular hard rubber. A core material, black in color, 8 pounds per cubic foot density (including skin),

Note 22. Cellular cellulose acetate. An extruded, unoriented, multi–cellular form of cellulose acetate containing a small percentage of glass fiber as a filler, 7–8 pounds per cubic foot density (including skin).

Note 23, Heat–treated glass cloth. A glass cloth that has been heated to a temperature sufficient to char the lubricant retained from the weaving process.

Note 24. Glass cloth. Heat–cleaned cloth chemically treated with a chrome complex bath after the lubricant has been completely removed by exposure to a high temperature.

Note 25. Glass–cloth honeycomb. Honeycomb core material with 3/16–inch hexagonal cells, made by impregnating glass cloth with resin to give a density of 7 to LO pounds per cubic foot.

Note 26. Cotton–cloth honeycomb. A 4–ounce cotton sheeting impregnated with a phenolic–type resin to a density of approximately 3.75 pounds per cubic foot. 3/8–inch to 7/16-inch hexagonal–cell size.

Z M 74051 F

Figure 1.--General view of cutting and inspecting end-grain balsa slabs.

Figure 2.--End-grain balsa slab showing variation in width of growth rings.

ZM 74052 F

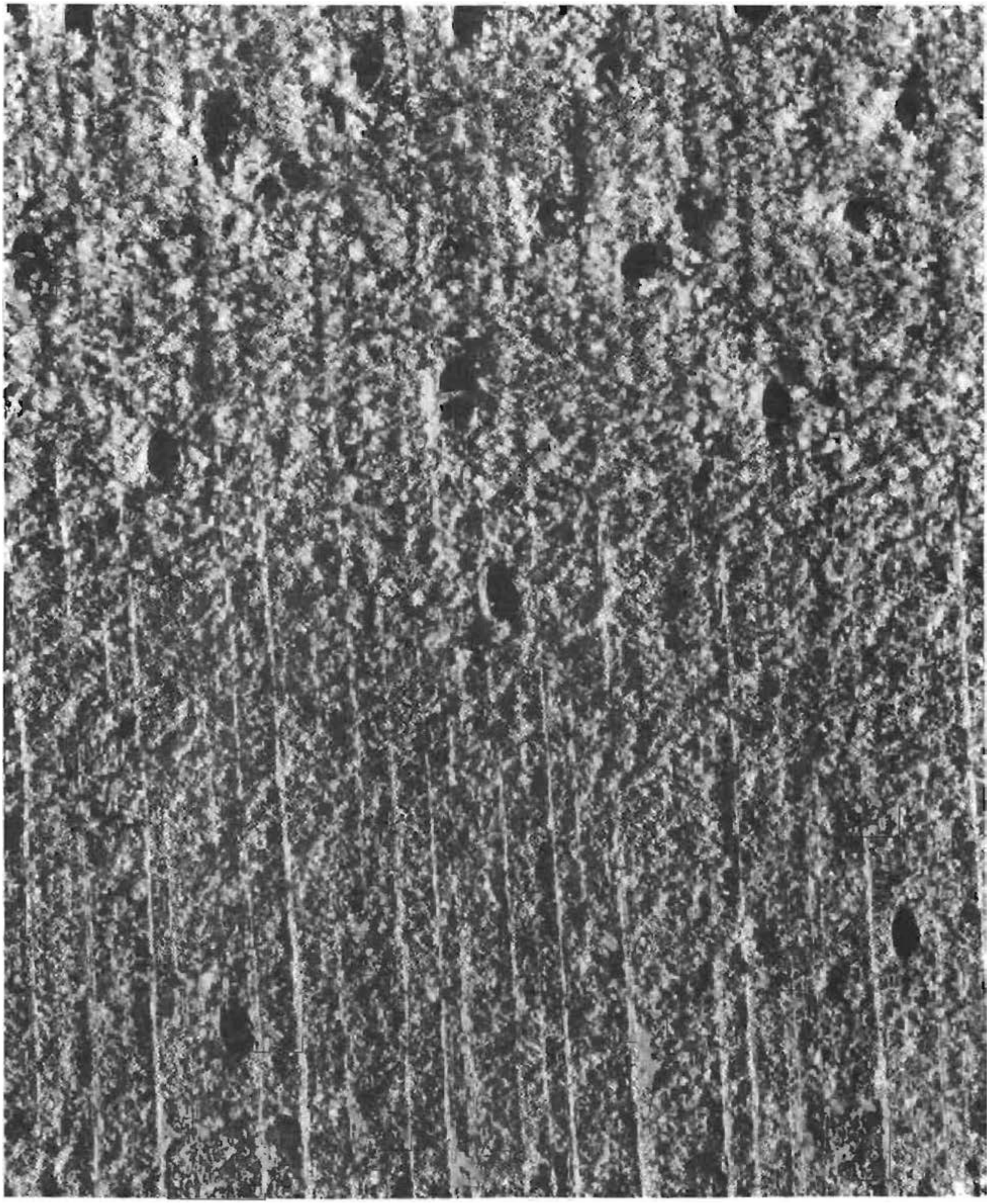


Figure 3.--Photomicrograph of sawed end-grain balsa slab. Lower half was low-density material and produced a valley in the surface, while upper half was higher-density growth ring, which produced a slightly raised surface when sawn.

Z M 74053 F

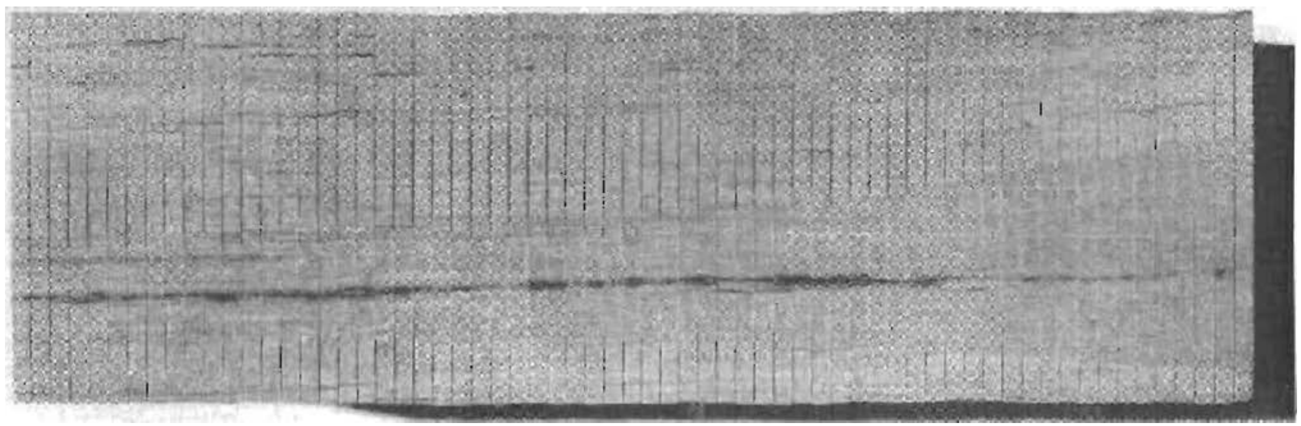


Figure 4.--Balsa plank after sawing on circular saw showing variation in thickness of slabs when cuts are made across bands of "corcho."

Z M 74054 F

Figure 5.--Special high-frequency gluing machine developed at the Forest Products Laboratory for edge gluing low-density cores.

Z M 74055 F

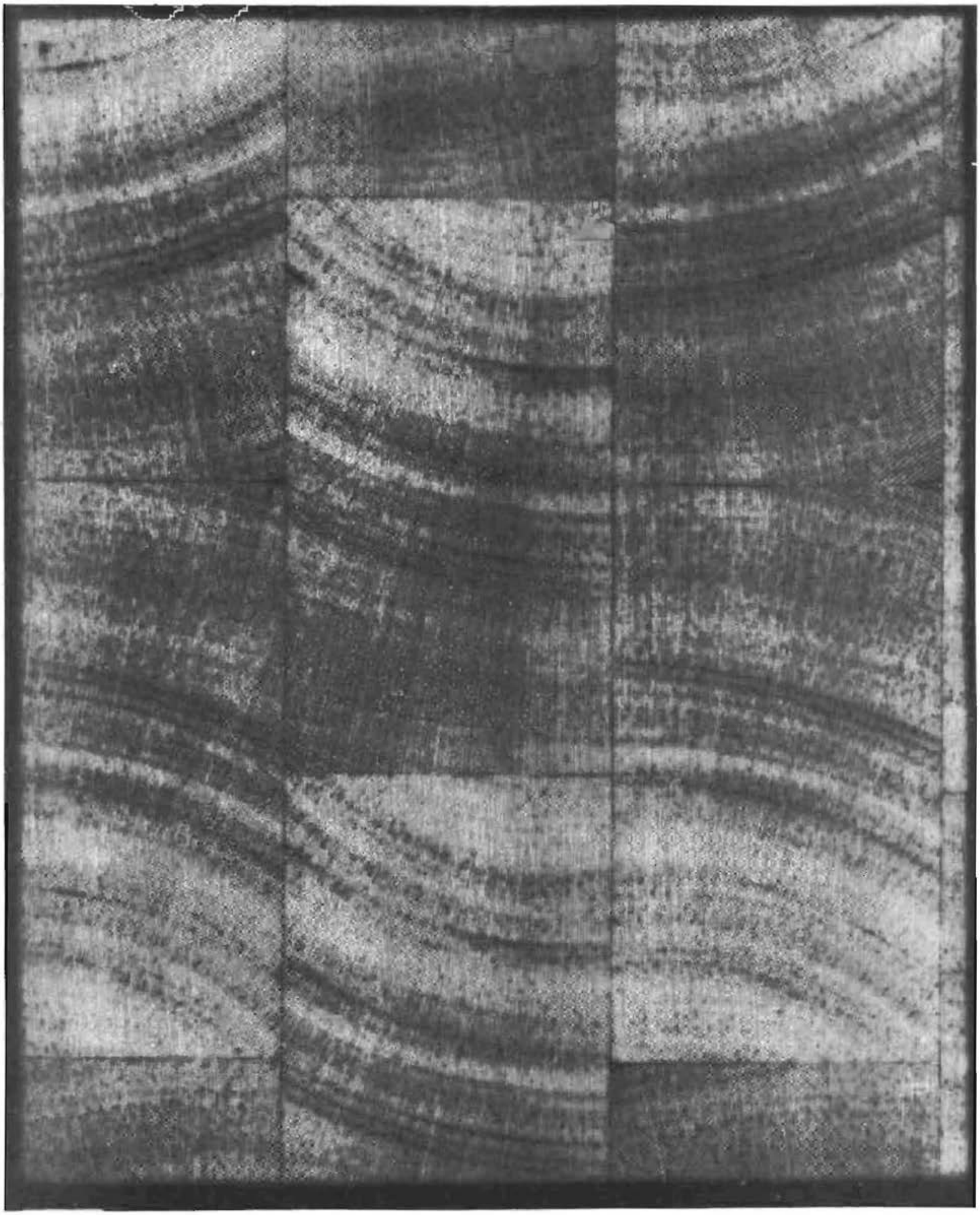
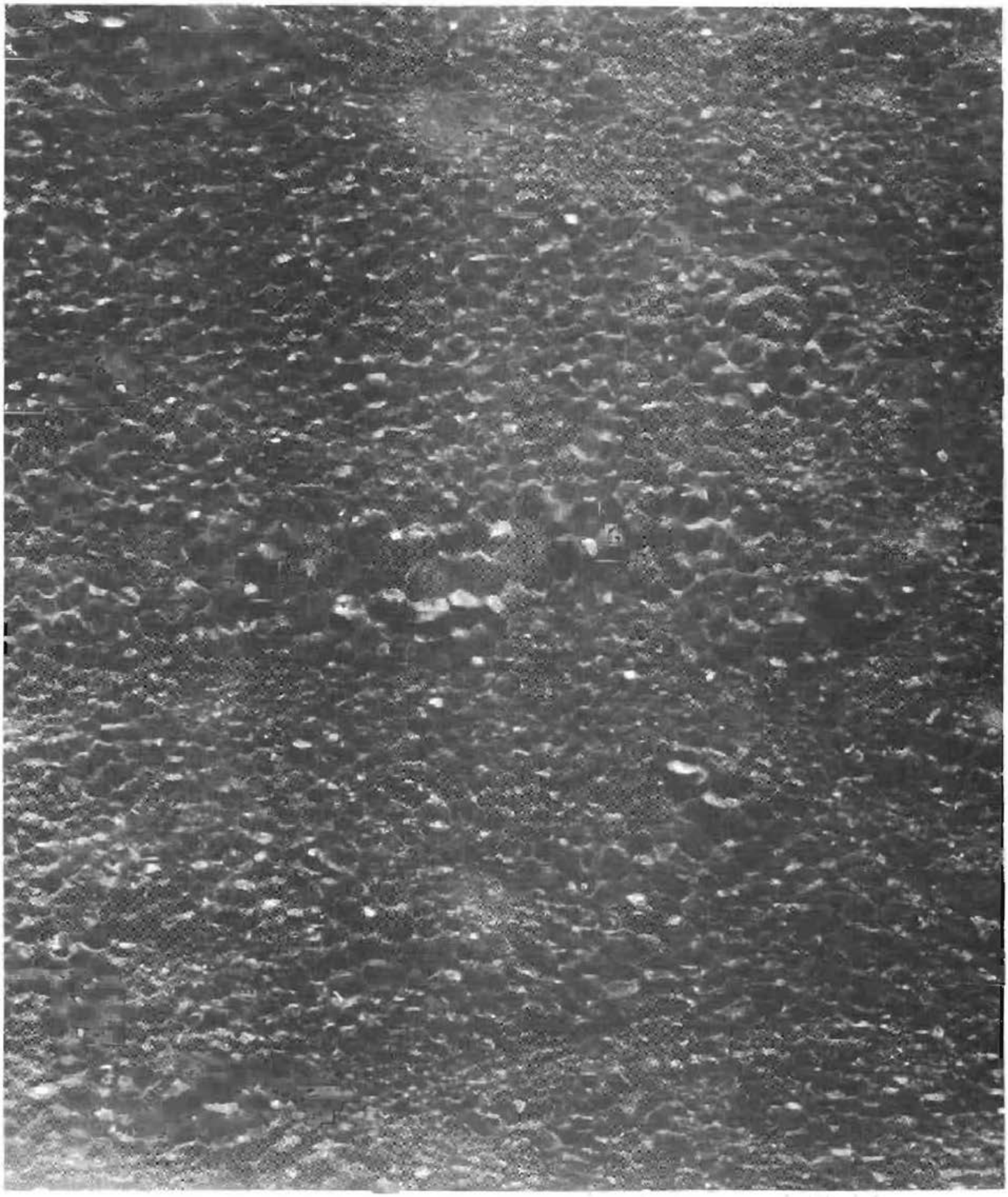
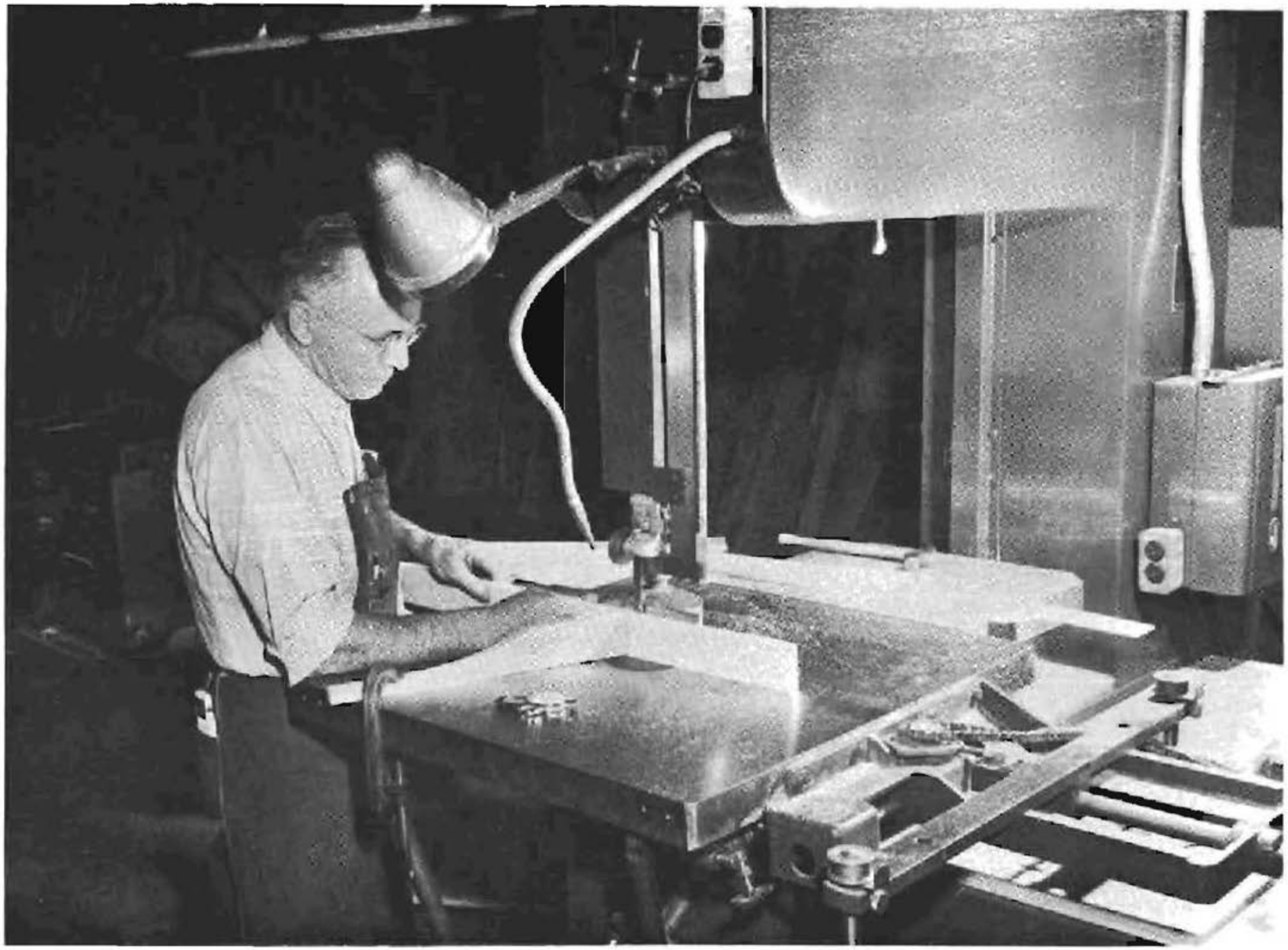


Figure 6.--End-grain balsa core of uniform density in the range of 6 to 9 pounds per cubic foot.

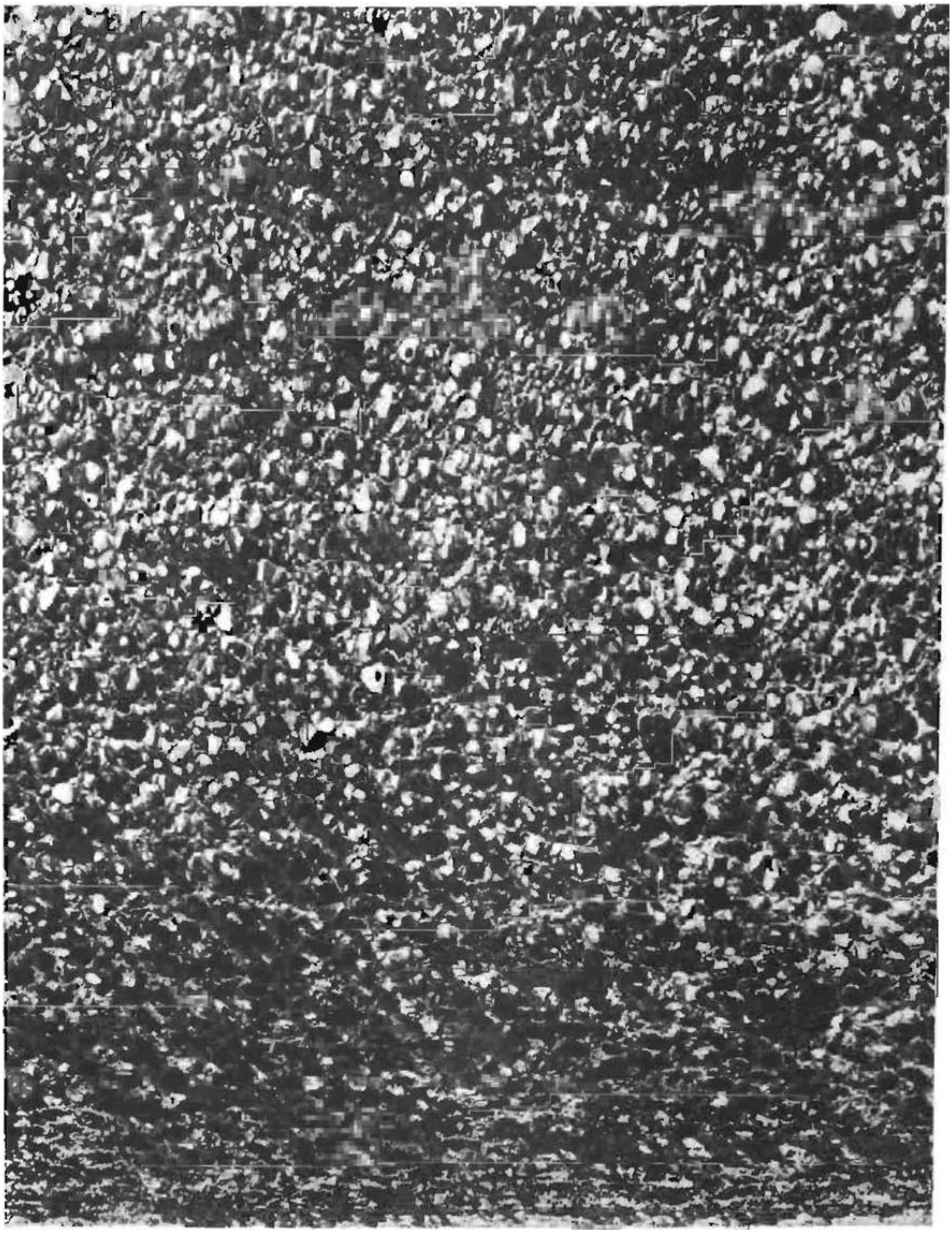
Z M 74056 F





Z M 74058 F

Figure 8.--Sawing equipment used on cellular cellulose acetate.



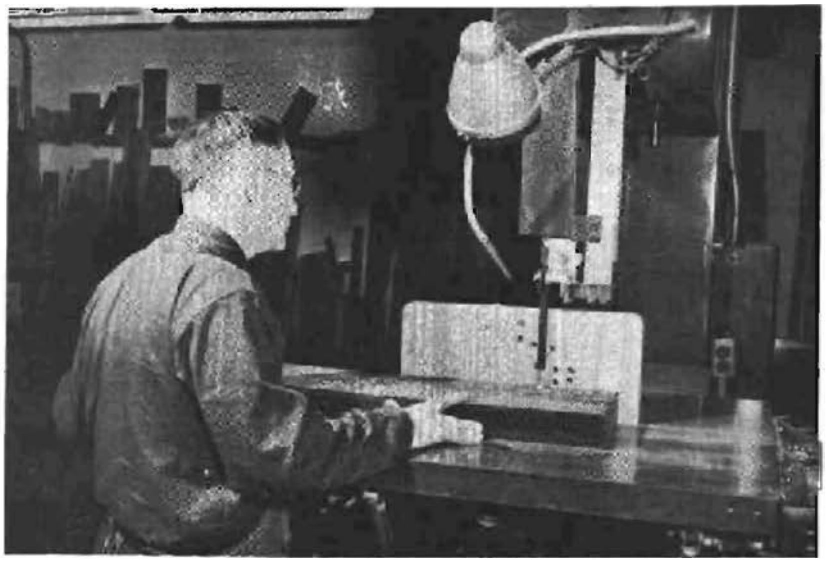


Figure 10.--Band saw set-up used for cutting paper honeycomb.

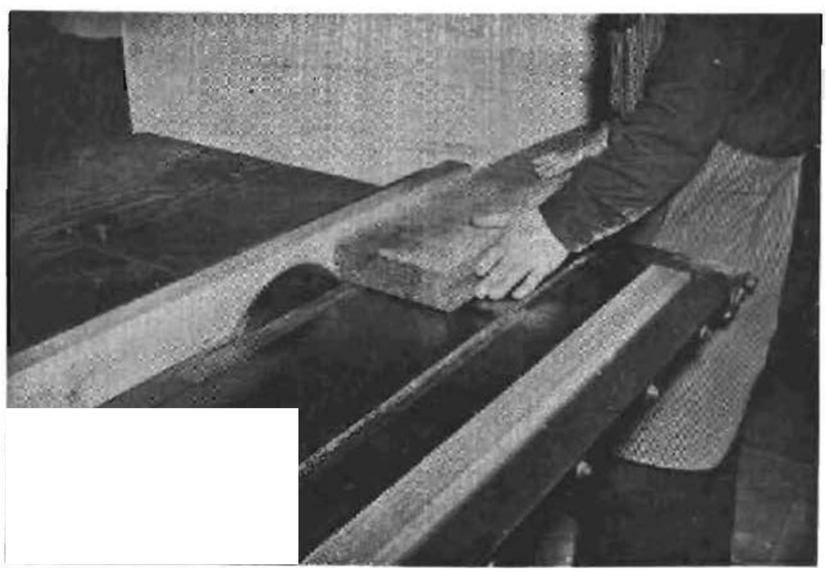


Figure 11.--Circular saw set-up used for cutting paper honeycomb.

Z M 74060 F

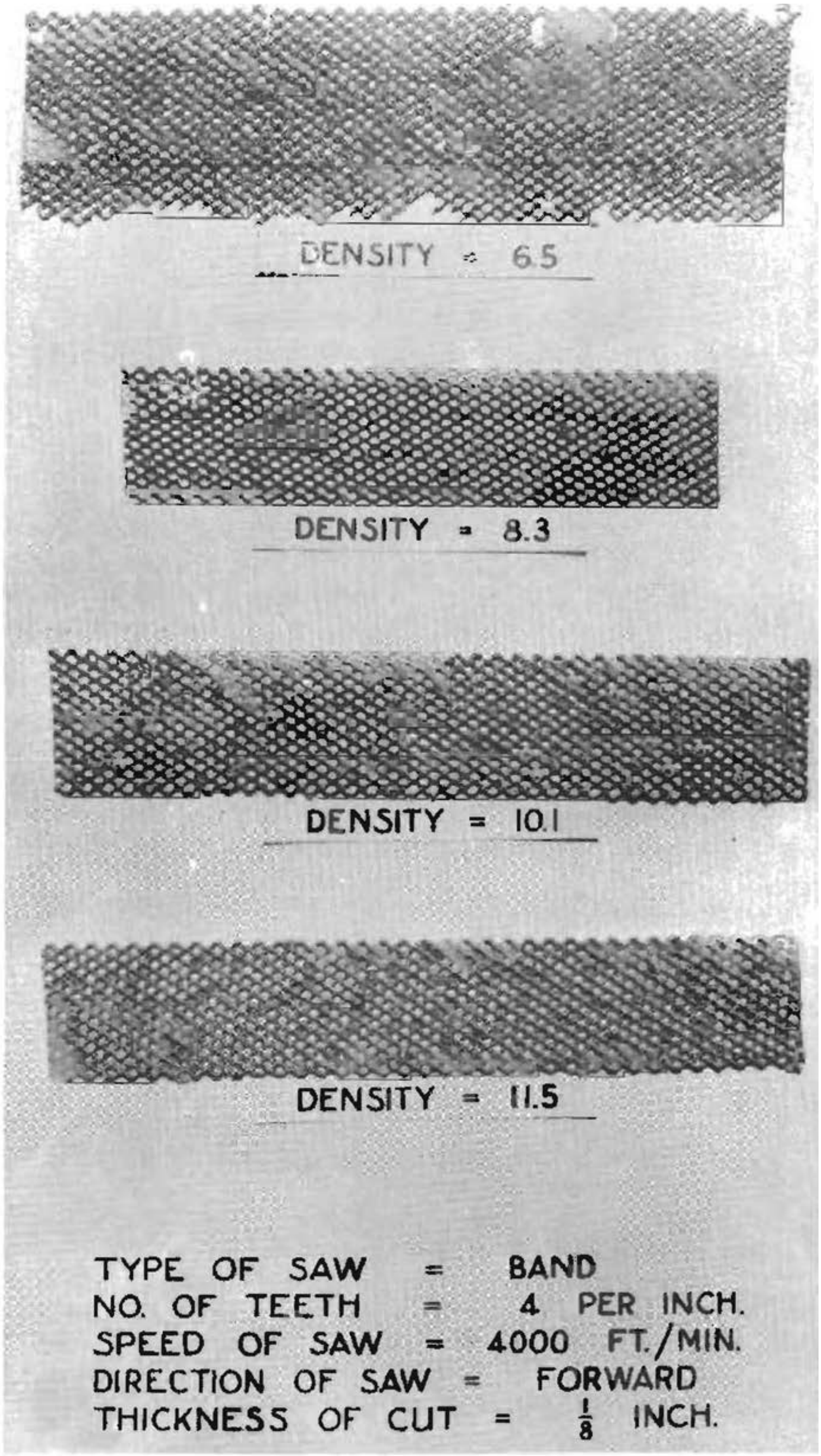


Figure 12.--Paper honeycomb showing the effect of density on cutting with a band saw.

Z M 74001 F

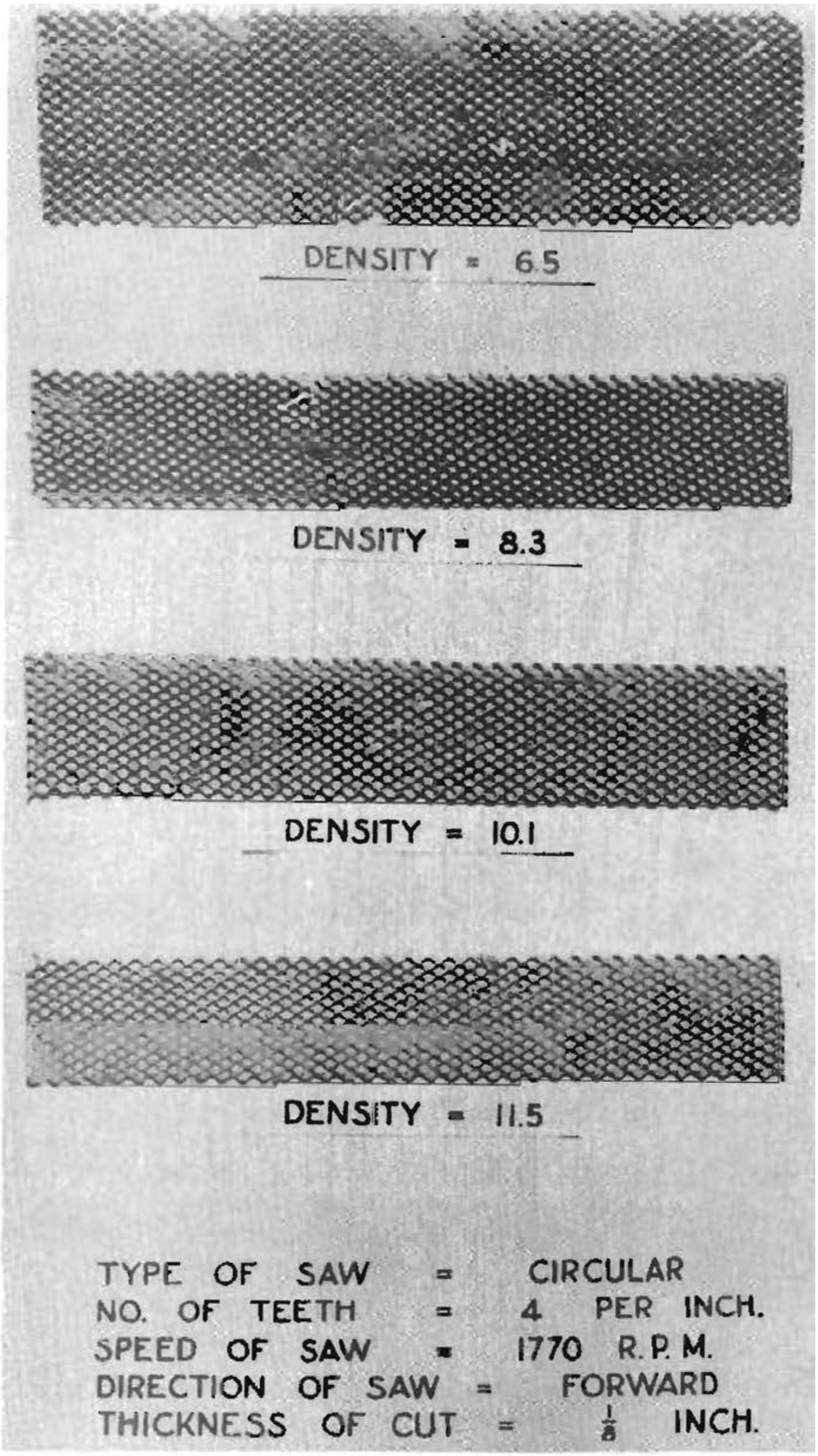
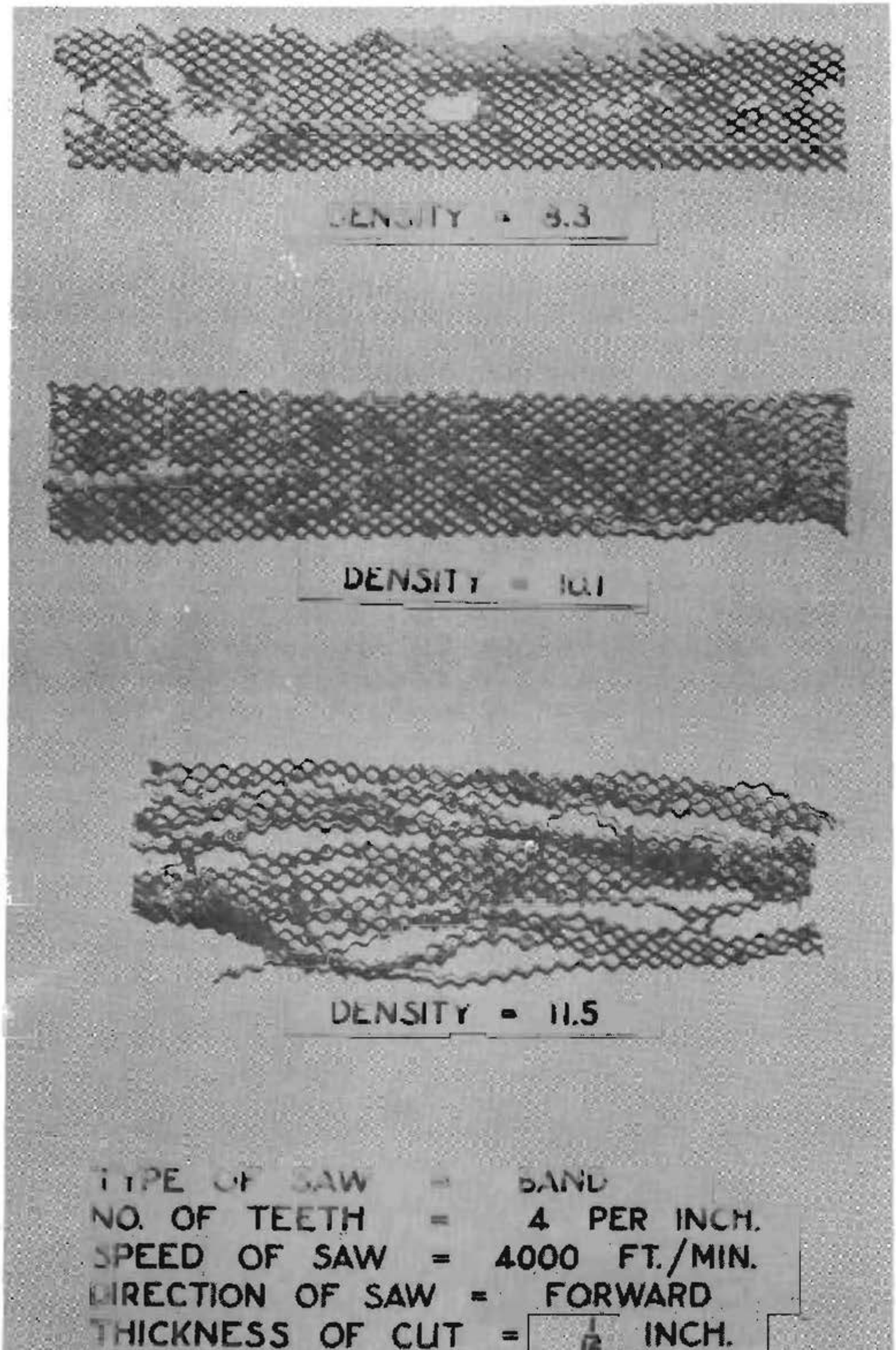


Figure 13.--Paper honeycomb showing the effect of density on cutting with a circular saw.

Z M 74062 F


DENSITY = 8.3
DENSITY = 10.1
DENSITY = 11.5
TYPE OF SAW = BAND
NO. OF TEETH = 4 PER INCH.
SPEED OF SAW = 4000 FT./MIN.
DIRECTION OF SAW = FORWARD
THICKNESS OF CUT = 1/16 INCH.

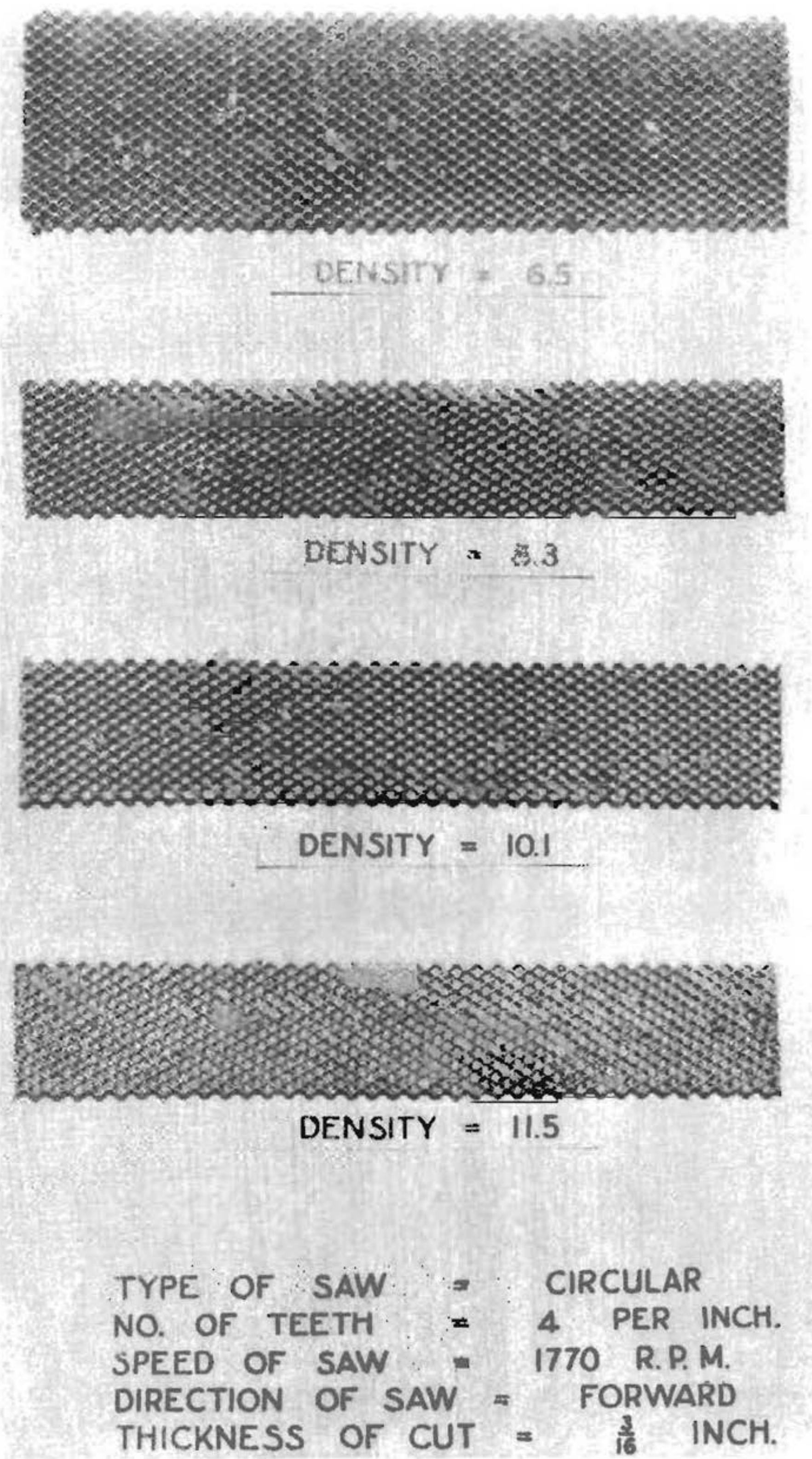


Figure 15.--Paper honeycomb showing effect of sawing to a thickness of 3/16 inch.

Z M 74064 F

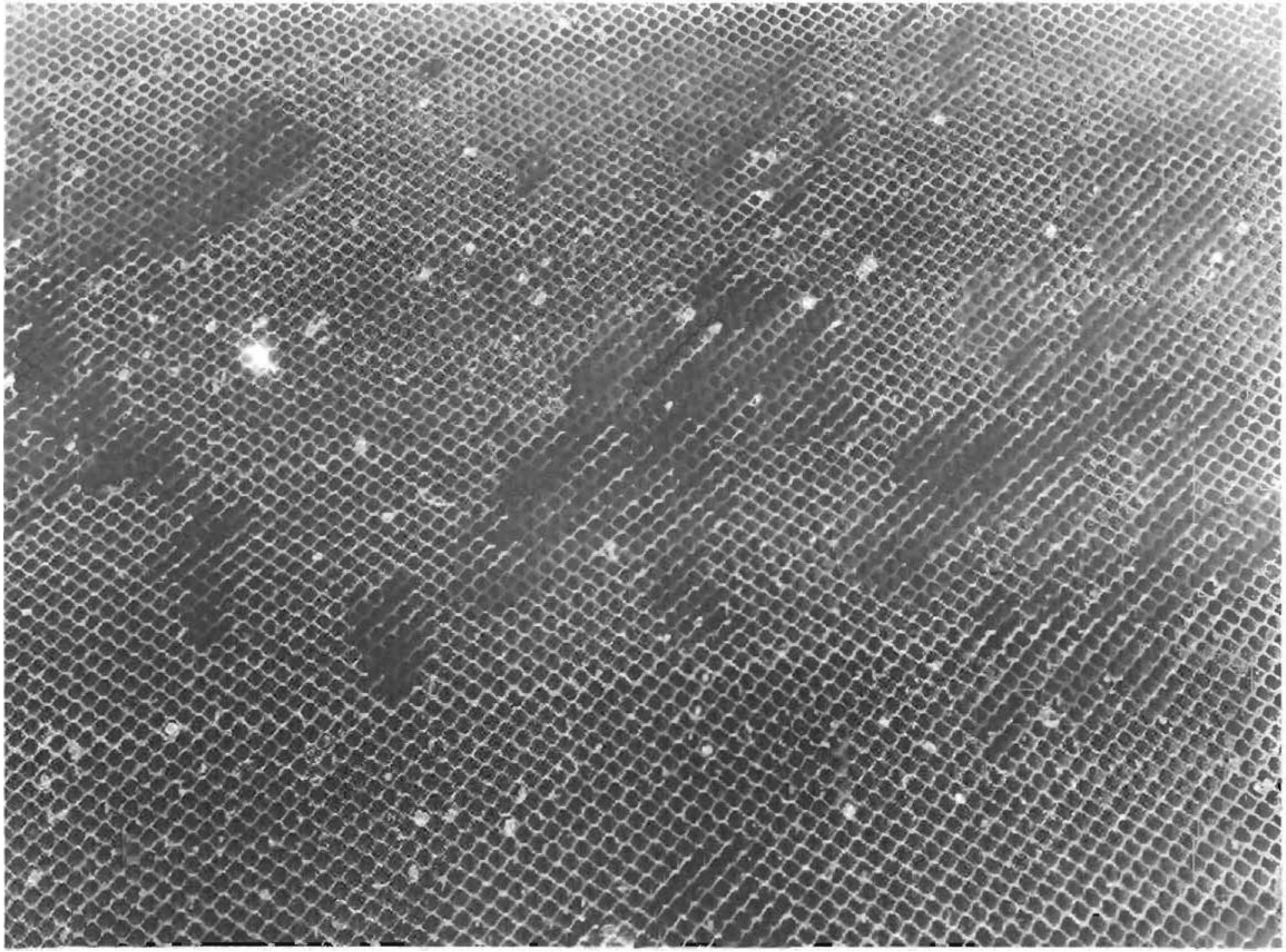


Figure 16.--Paper honeycomb core showing the surface obtained by cutting with a circular saw.

Z M 74085 F

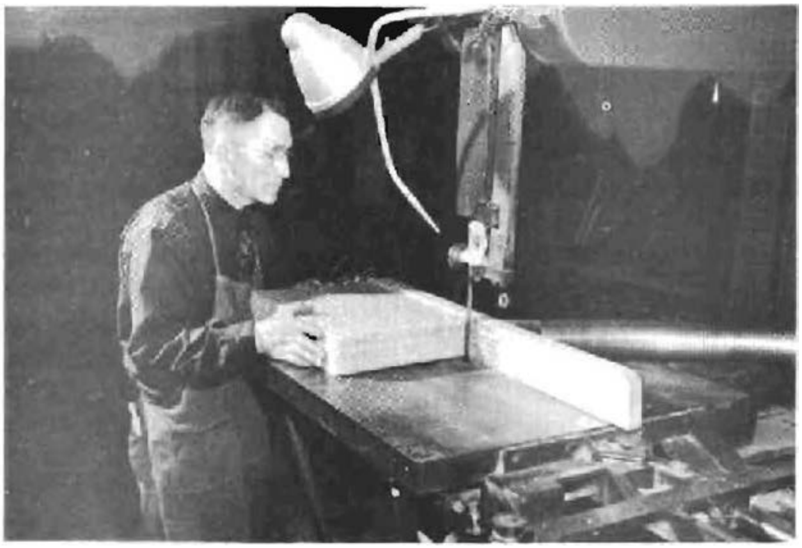


Figure 17.--Band saw set-up used for cutting glass cloth honeycomb.

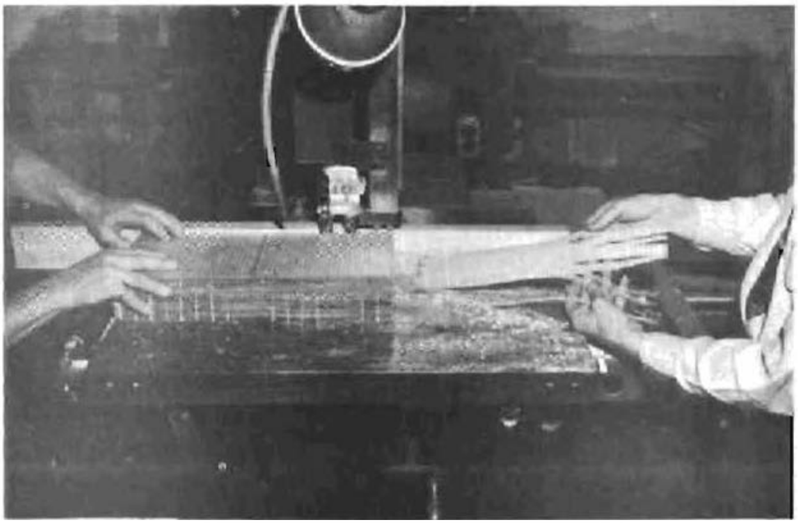
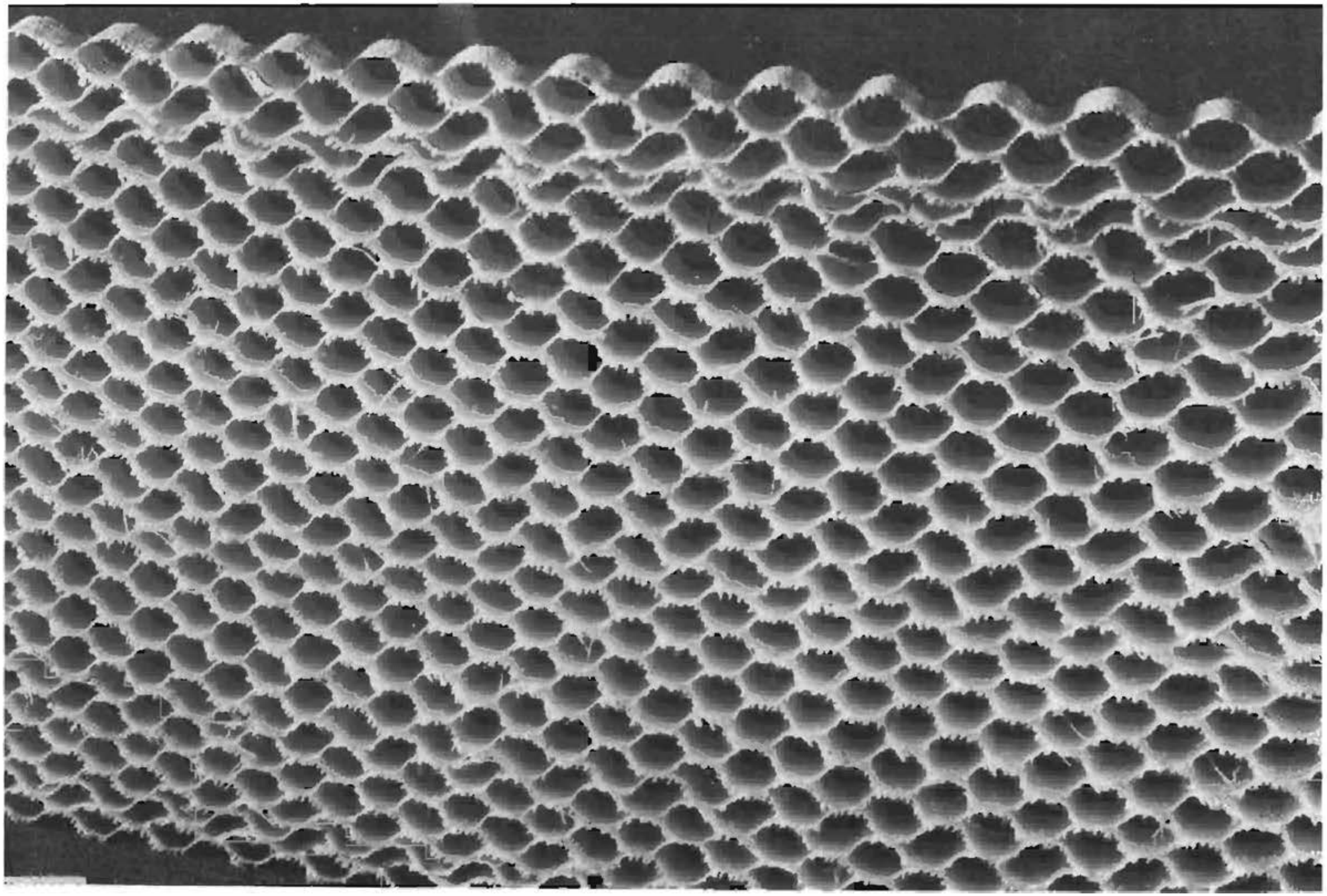


Figure 18.--Glass cloth honeycomb showing the effect of sawing thin sections on a band saw.

Z M 74066 F



Z M 74067 F

Figure 19.--Glass-cloth honeycomb showing the fuzzy surface caused by a band saw.

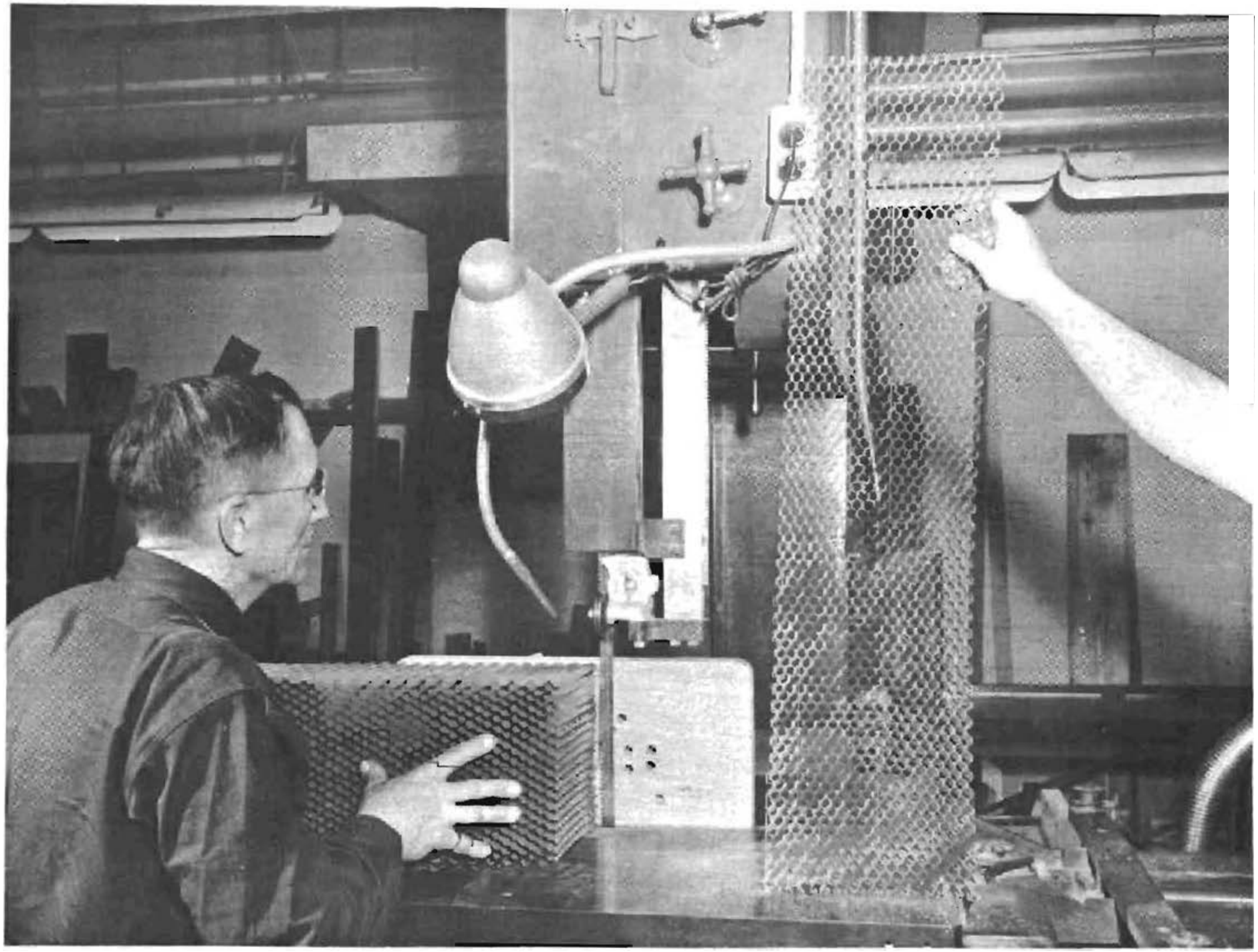


Figure 20.--Band-saw set-up used for cutting

Z M 74068 F

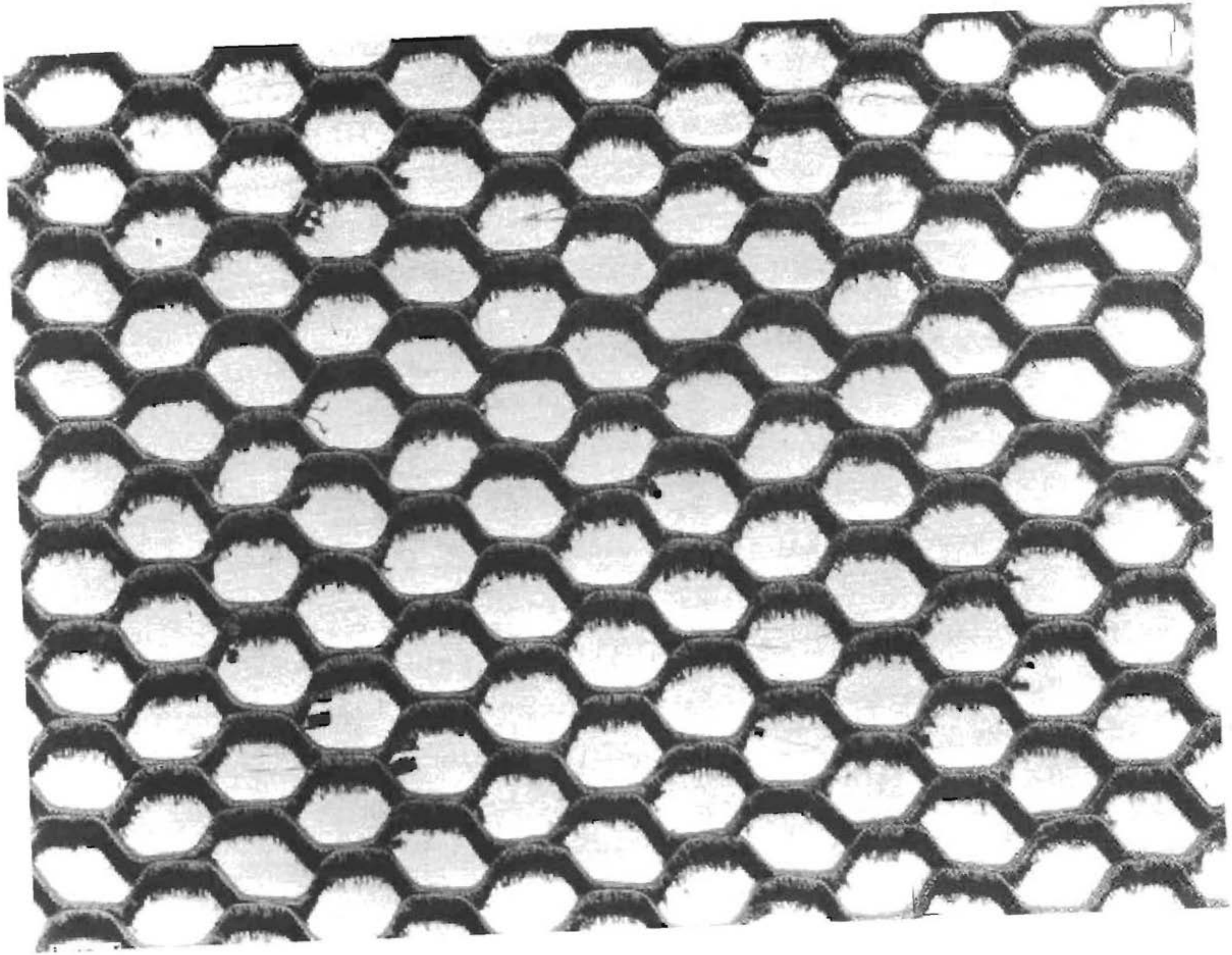


Figure 21.--Cotton-cloth honeycomb showing the character of the surface produced by a 14-tooth band saw.

Z M 74069 F

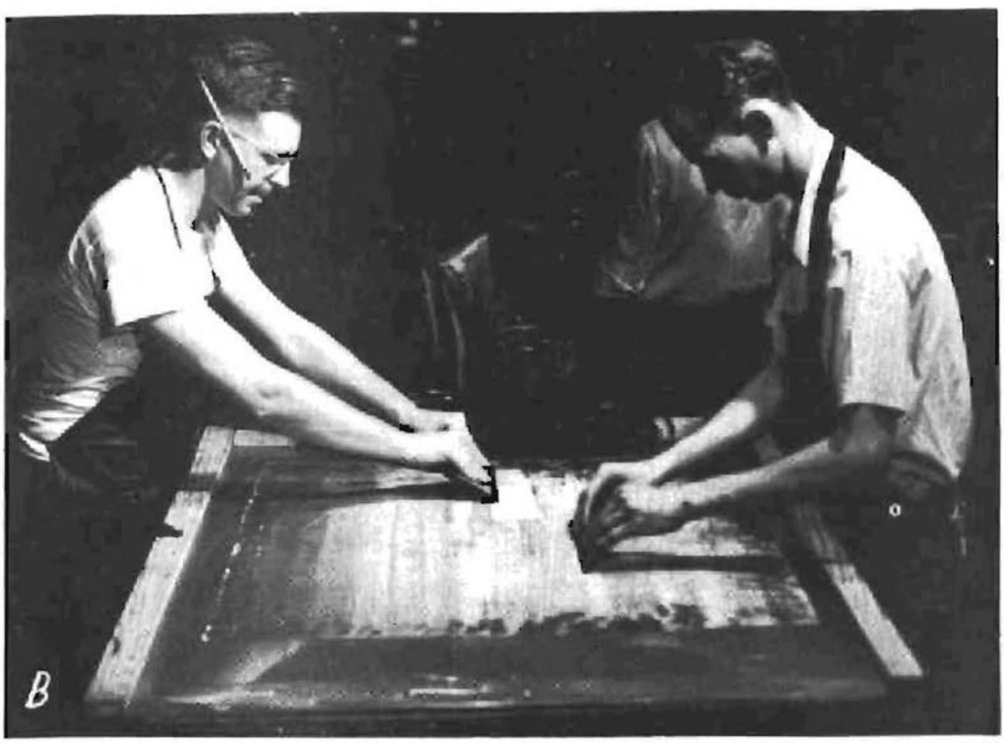
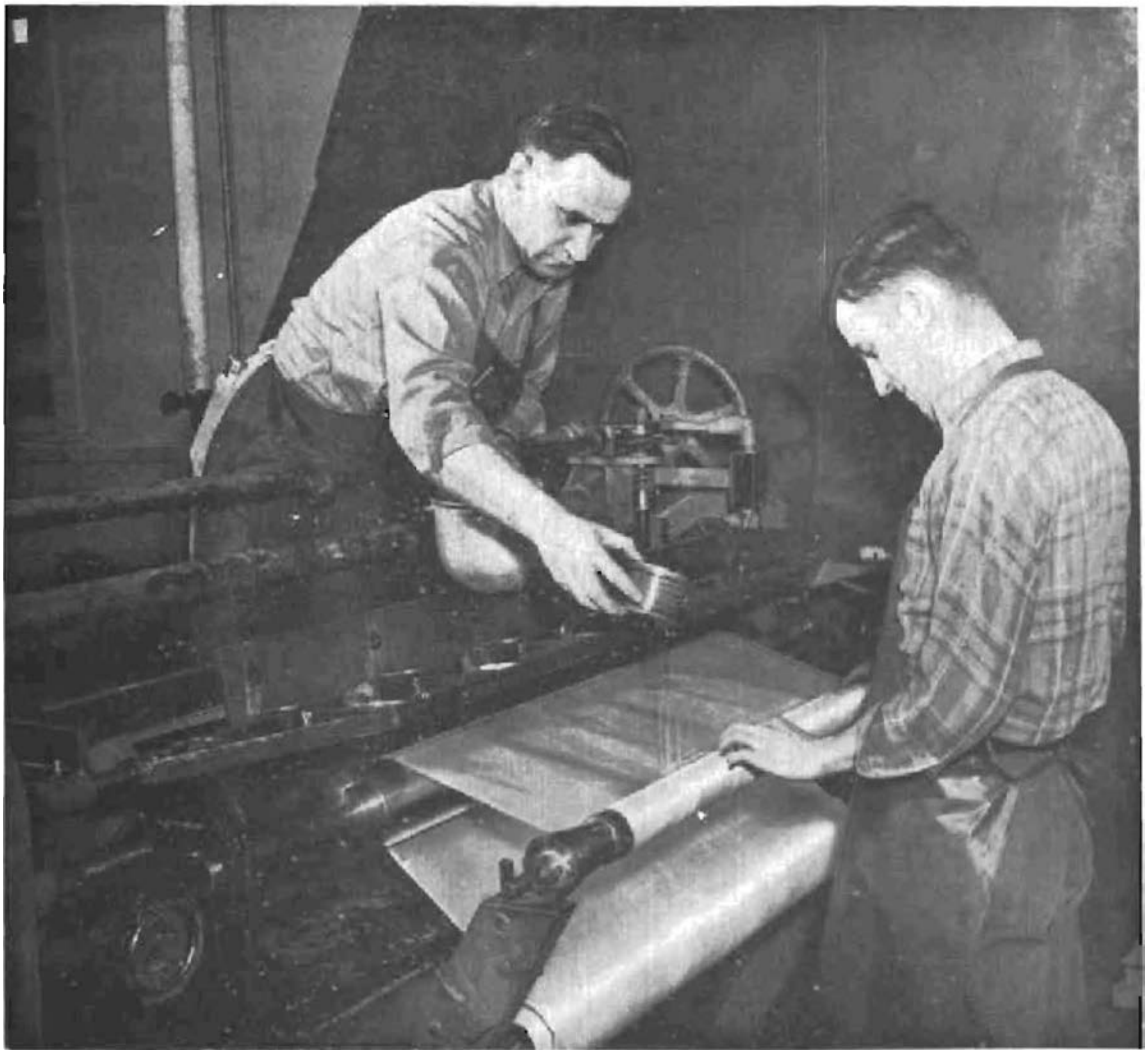


Figure 22.--Procedure used in applying high-viscosity laminating resin A to glass cloth by hand spreading. A Applying film of resin to stainless-steel sheet. B. Working glass cloth into resin film to impregnate the cloth.

Z M 74070 F

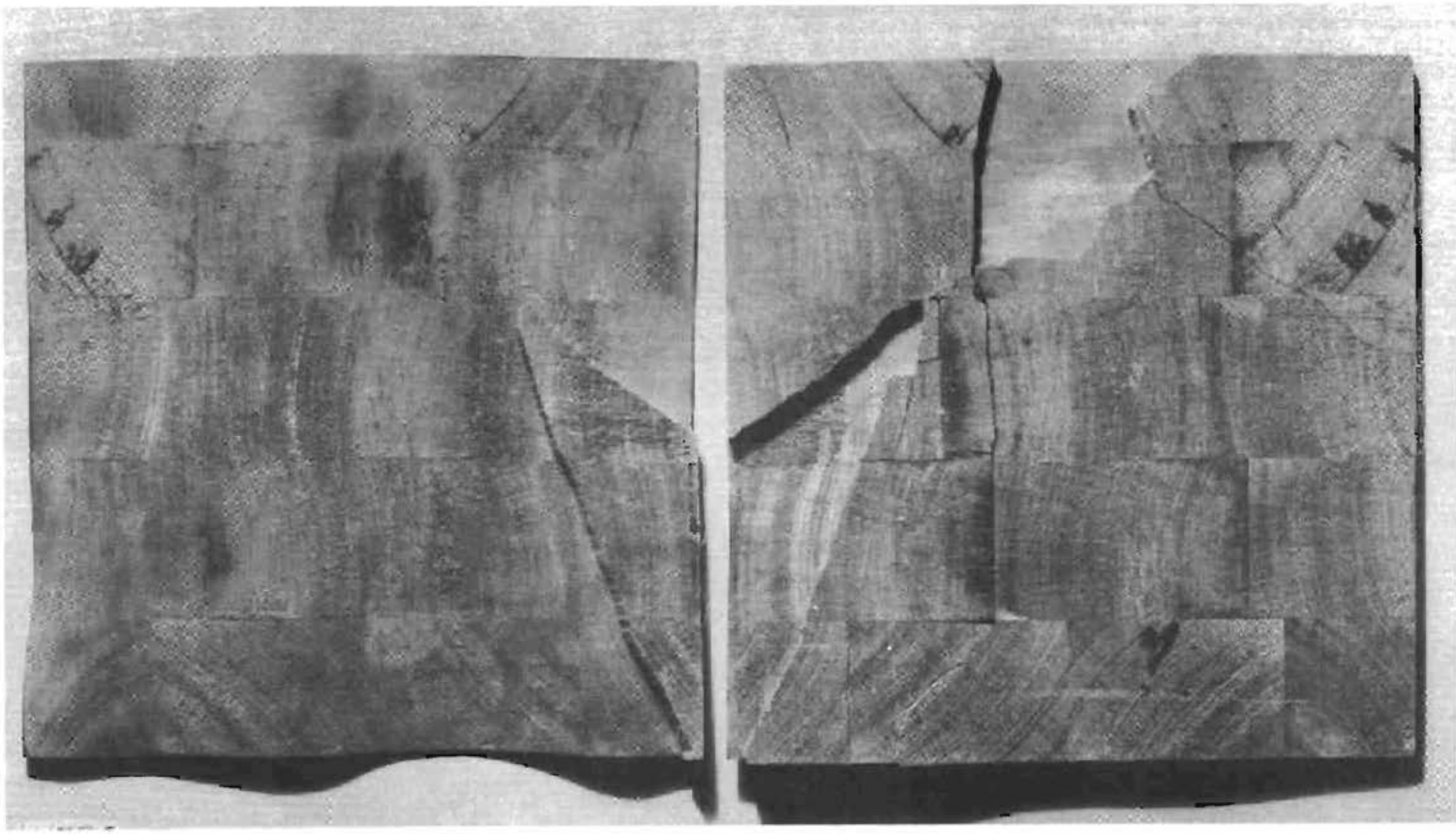
Figure 23.--High viscosity, laminating resin being spread on glass cloth with a mechanical spreader.

Z M 74071 F



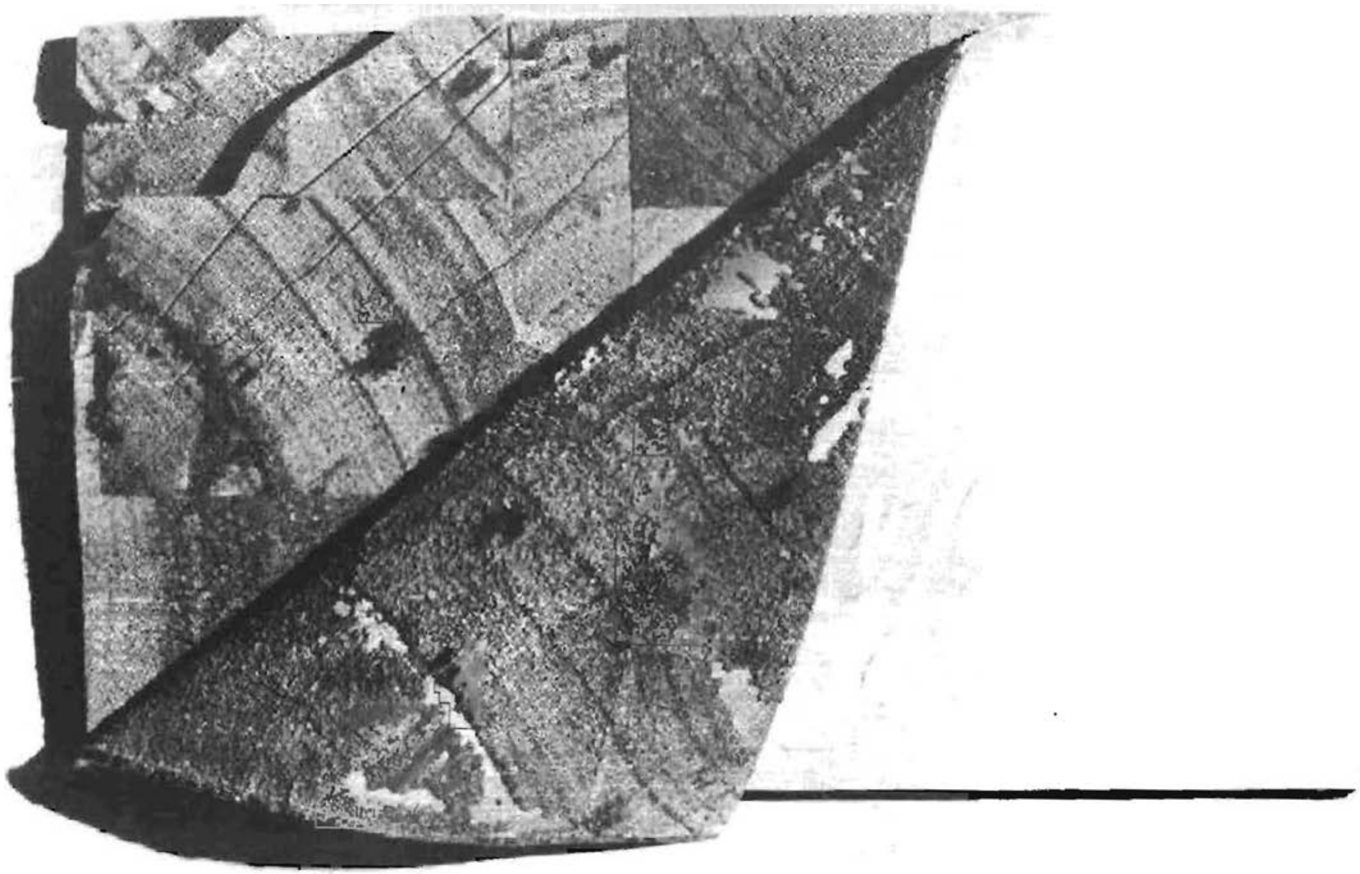
Z M 74072 F

Figure 24.--Low viscosity laminating resin being spread on glass cloth.



Z M 74073 F

Figure 25.--Face stripped from an aluminum-balsa sandwich glued with adhesive F. Smooth areas on face at left indicate lack of contact with core during pressing. A rubber cushion would prevent this.



Z M 74074 F

Figure 26.--Face partially stripped from an aluminum-balsa sandwich glued with adhesive G. Good contact between face and core was obtained due to flow of the adhesive.

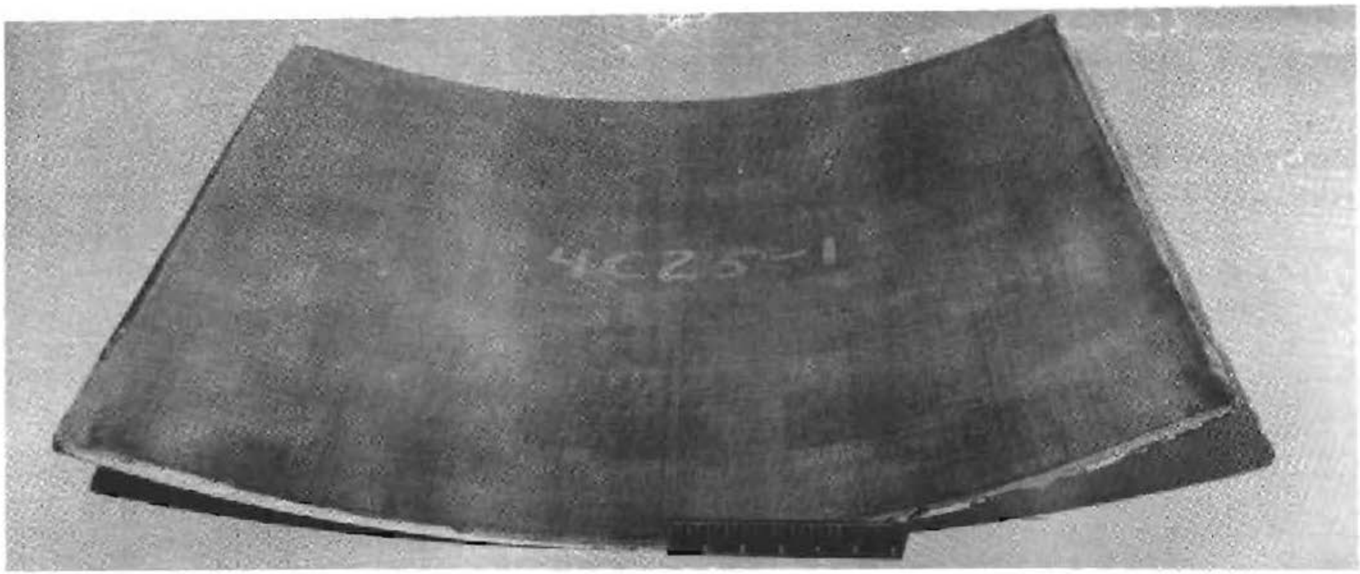


Figure 27.--Curved 1/8- by 32-inch glass cloth-balsa sandwich showing spotty appearance of three-ply glass-cloth faces due to variations in density of balsa core.

Z M 74075 F

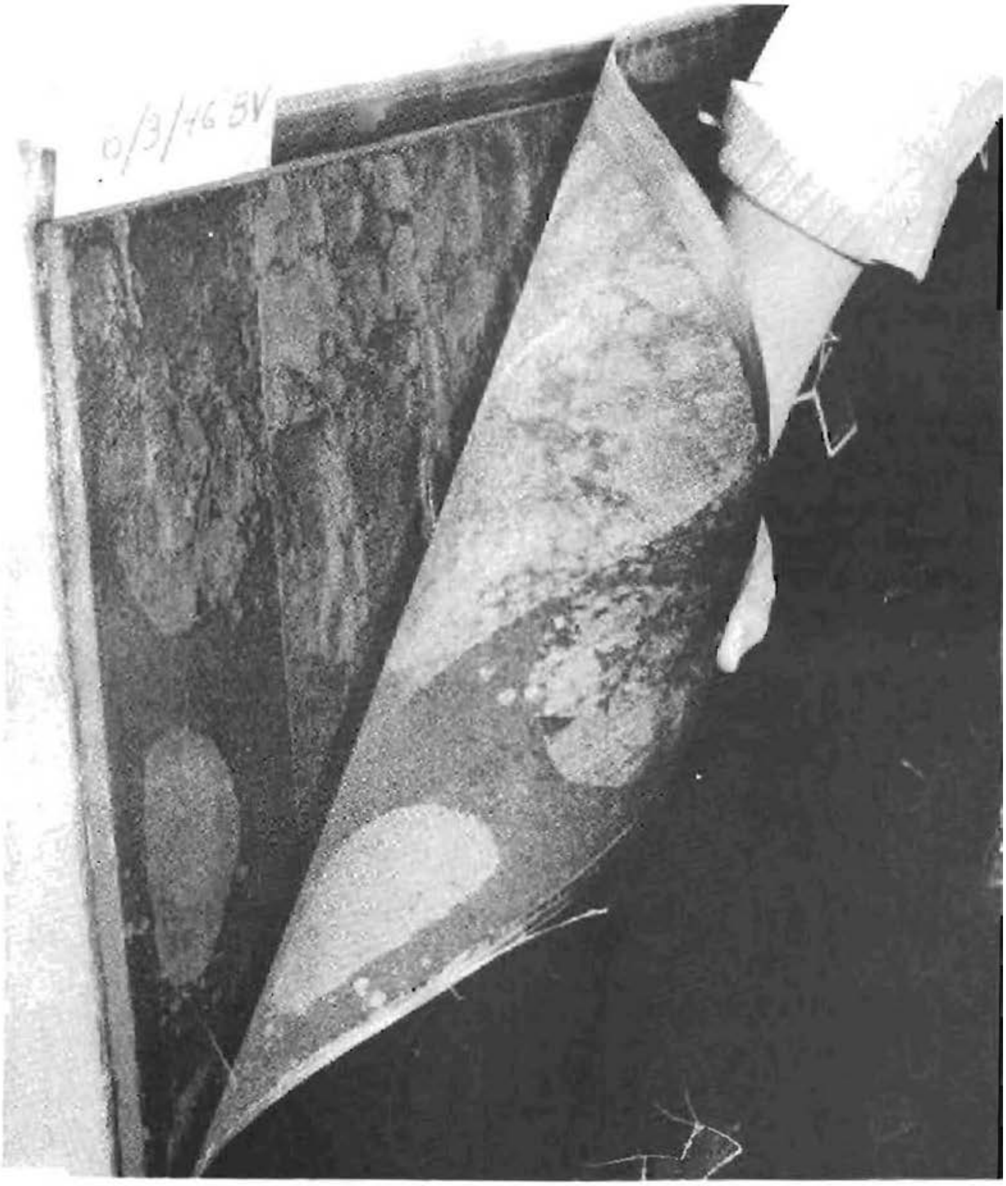


Figure 28.--Sandwich panel with glass-cloth faces and cellular hard rubber core showing blisters and crushing of the core during curing due to high catalyst content on the core.

Z M 74076 F

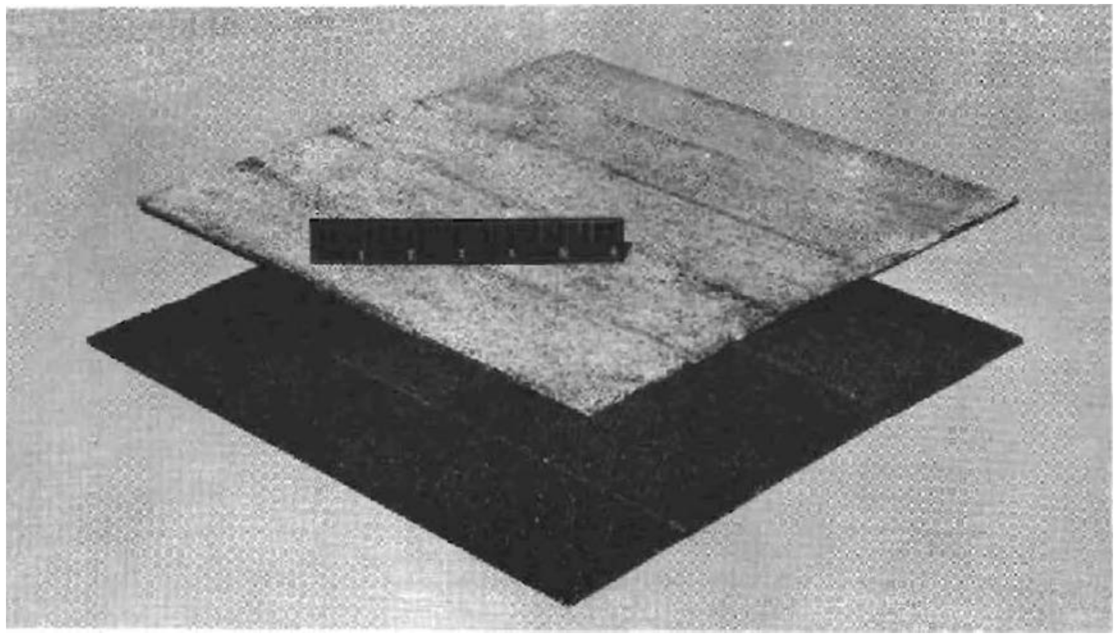


Figure 29.--One-eighth-inch cellular hard rubber cores showing appearance before (dark) and after (light) application of extra catalyst, benzoyl peroxide.

Z M 74077 F

Z M 74078 F

Figure 30.--Panel having slight curvature being molded on the convex side of a metal mold in a rubber bag.

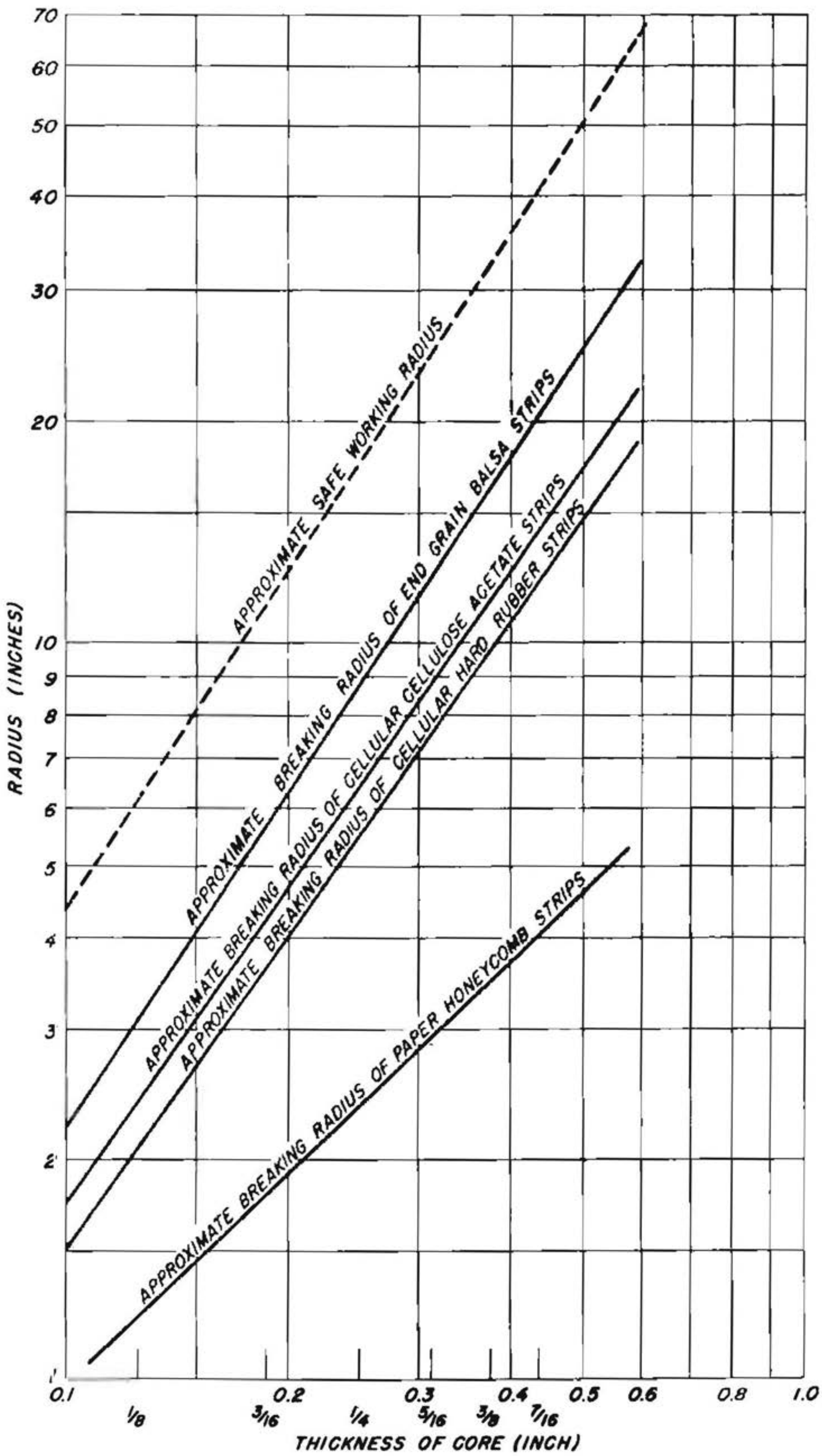


Figure 31.--Approximate breaking radii and safe working radii of balsa, cellular cellulose acetate, cellular hard rubber, and paper honeycomb cores.

Z M 72999 F

Figure 32.--End-grain balsa core, glued to one aluminum face, being bent in a sheet metal rolling machine.

Z M 74079 F

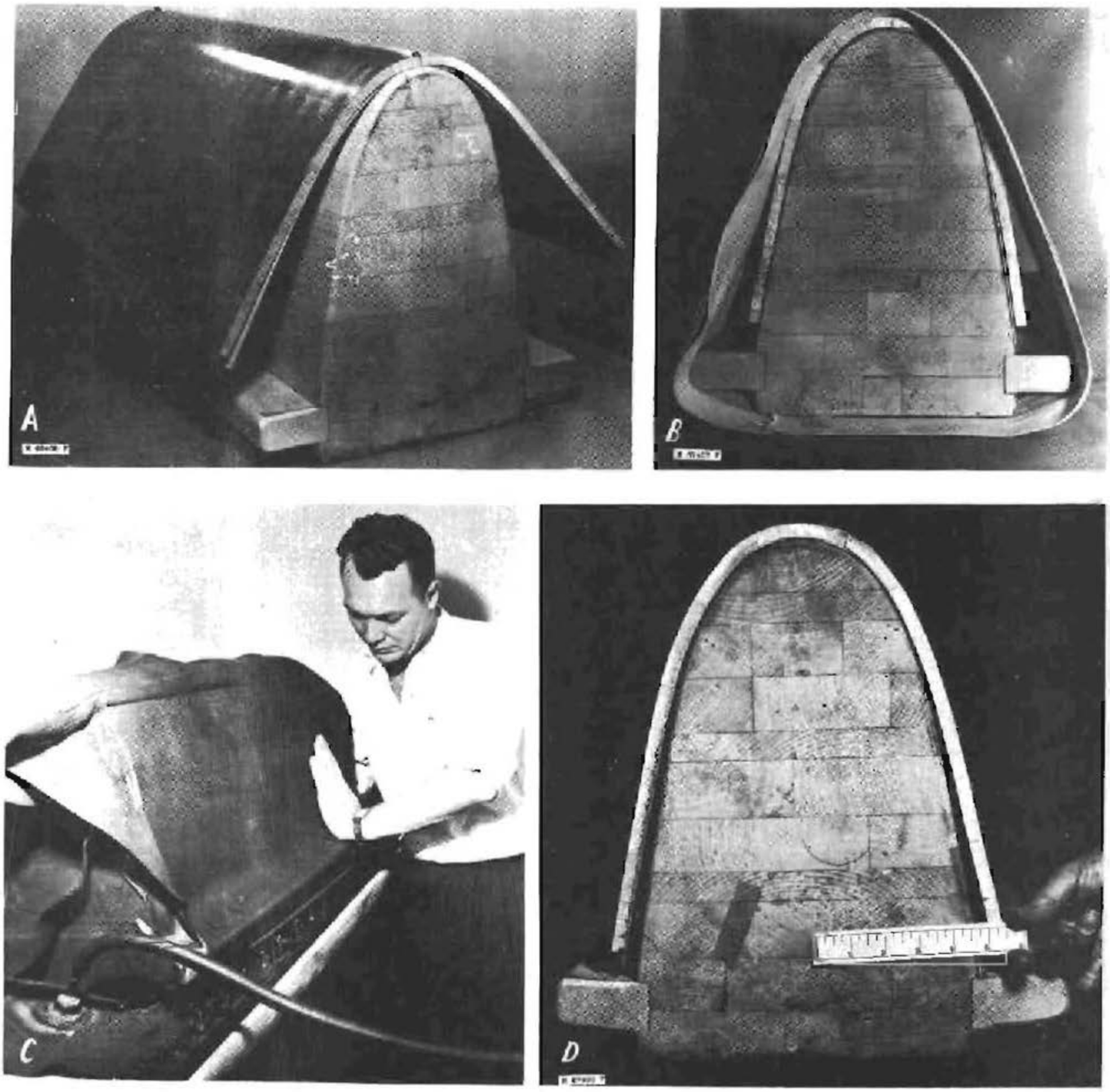


Figure 33.--Molding an aluminum-to-balsa panel on a male mold. A.-Preformed aluminum-balsa assembly held temporily in place on a male mold preparatory to molding to the inner face. B.-Canvas wrapping applied to assembly to provide additional pressure at the point of greatest curvature. C.-Vacuum being drawn on bag previous to the molding operation. D.-Difference in shape between the mold and the sandwich panel molded on its outer surface.

Z M 74080 F

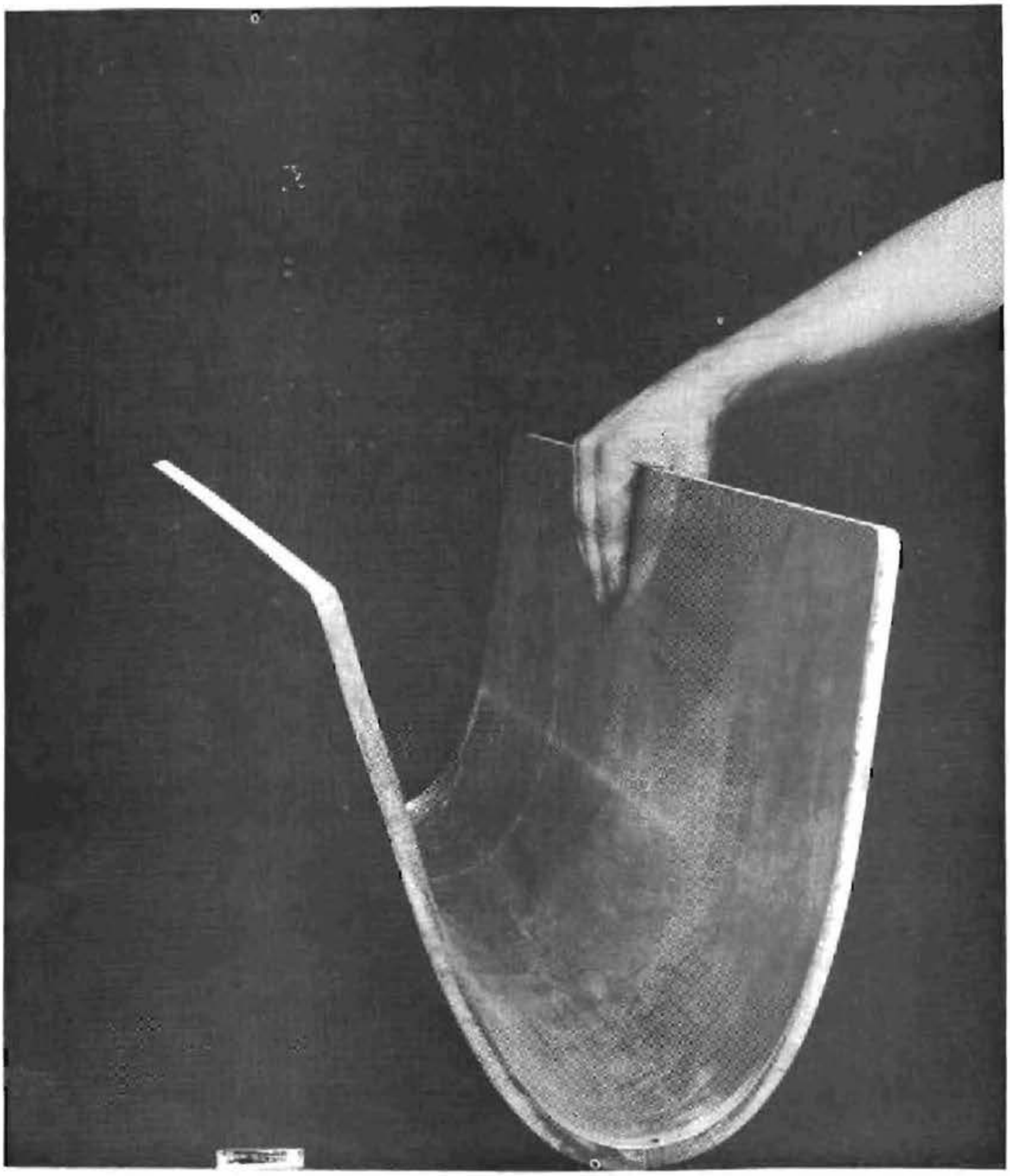


Figure 34.--Trimmed curved sandwich having aluminum faces on a 1/2-inch thick balsa core. Minimum radius is about 2-1/2 inches.

Z M 74081 F

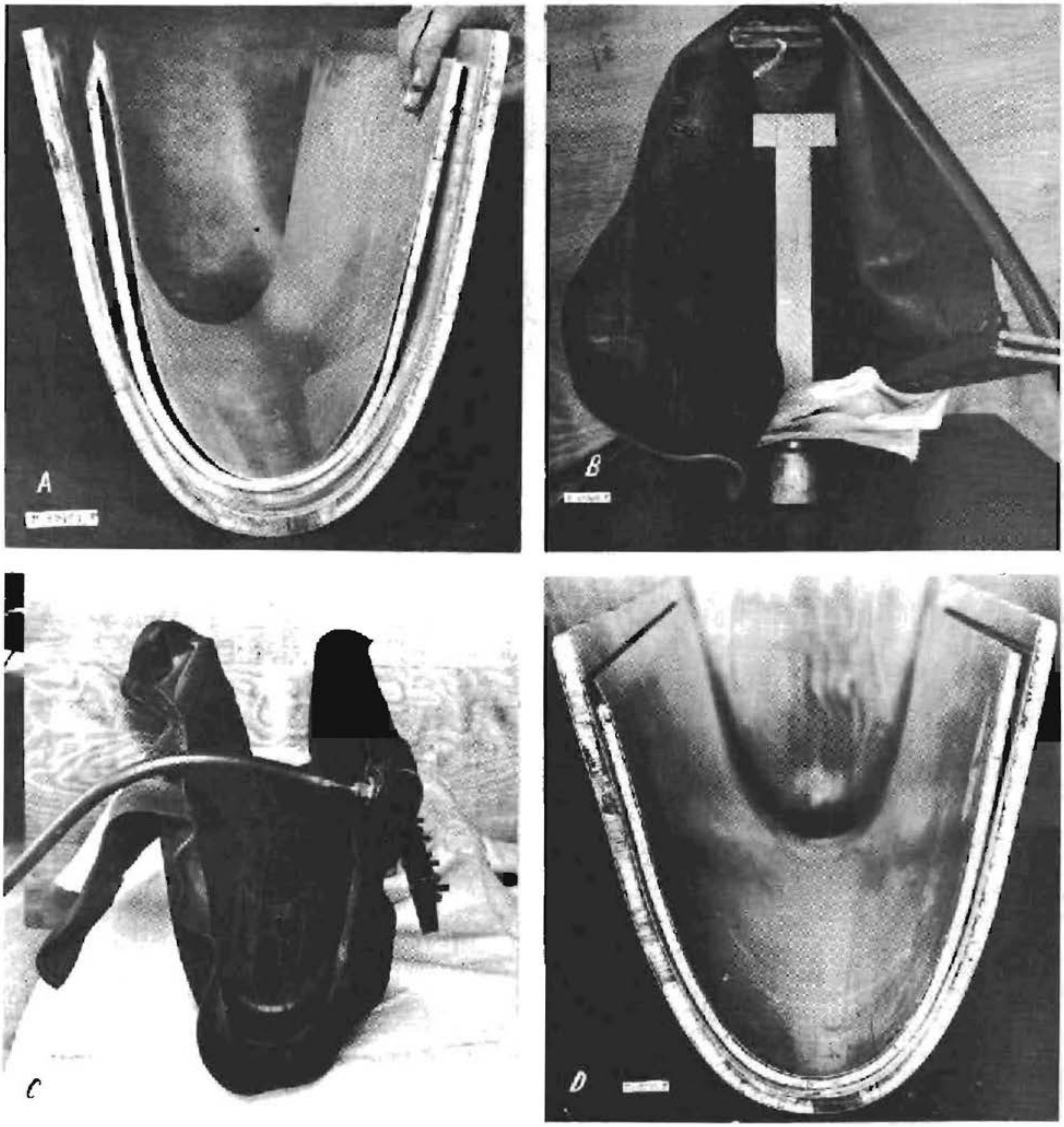


Figure 35.--Molding a sandwich panel on a female mold. A.-Preformed faces and core laid in female mold preparatory to gluing inner face in place. B.-Vacuum being drawn on bag after pressure is applied to inner curvature by means of a fire hose jig. C.-Vacuum completely drawn and fire hose jig removed. D.-Difference in shape between mold and product.

Z M 74082 F

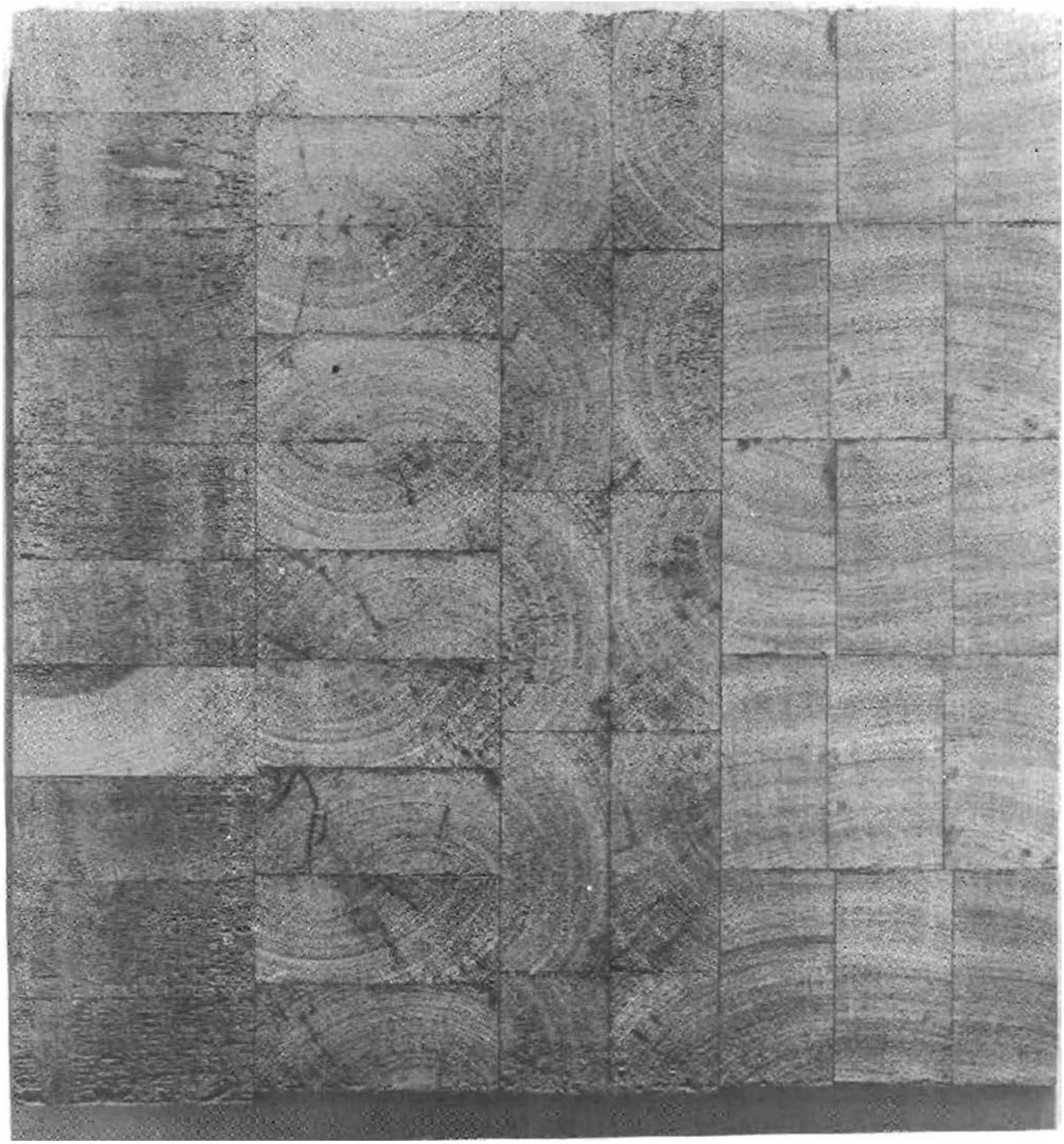


Figure 36.--End-grain balsa core after planing in a freshly sharpened cabinet planer operating at 3,600 revolutions per minute.

Z M 74083 F

Figure 37.--Knife coater used for applying resin to glass cloth.

Z M 74084 F

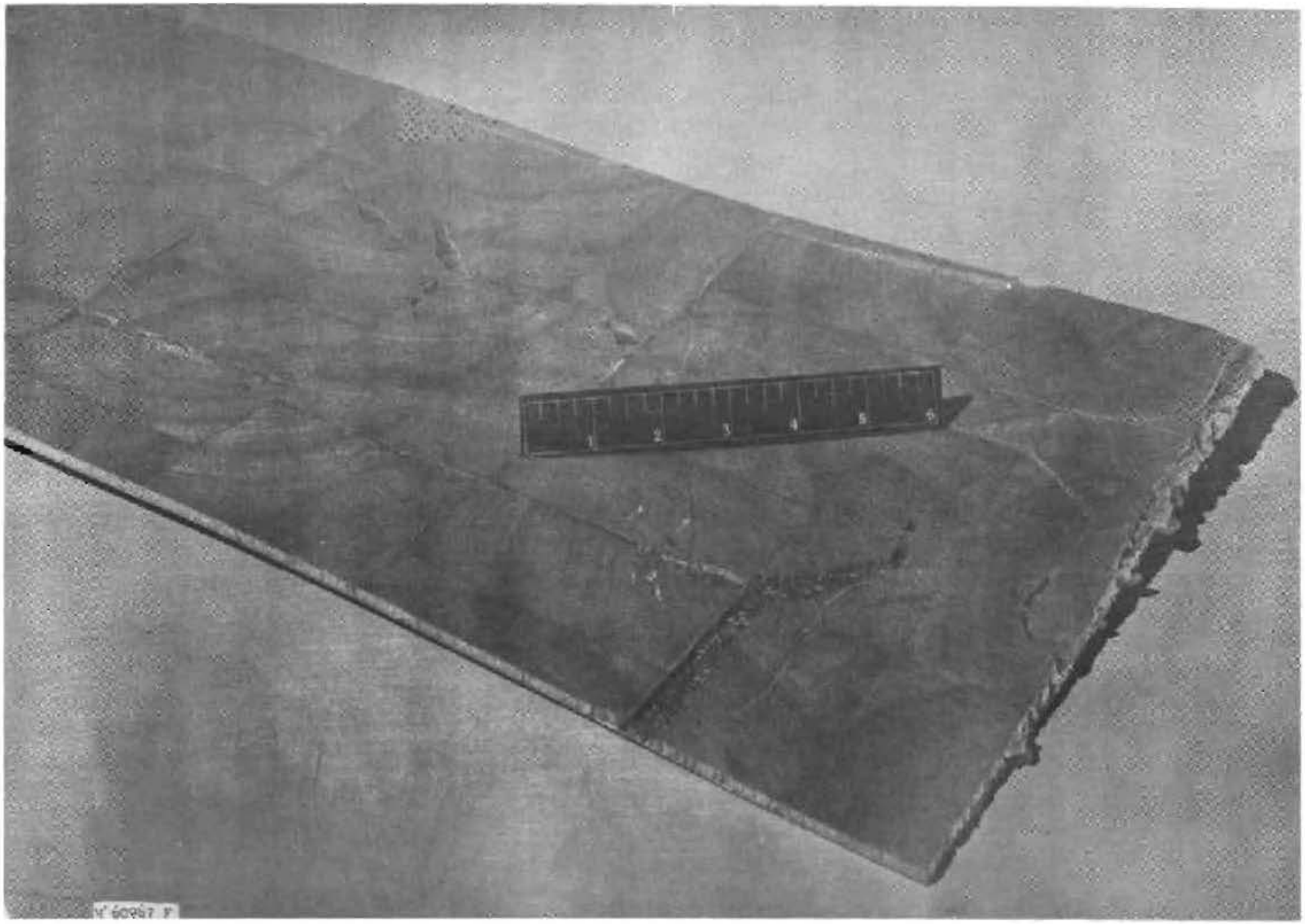


Figure 38.--Defects in panel caused by radial and tangential compression of end-grain balsa core due to high resin content of glass-cloth faces, high pressure, and possibly high curing temperature. Eight-ply faces of approximately 55 percent resin content were pressed at a pressure of 75 pounds per square inch pressure and 250° F. to a 3/16-inch end-grain balsa core.

Z M 74085 F

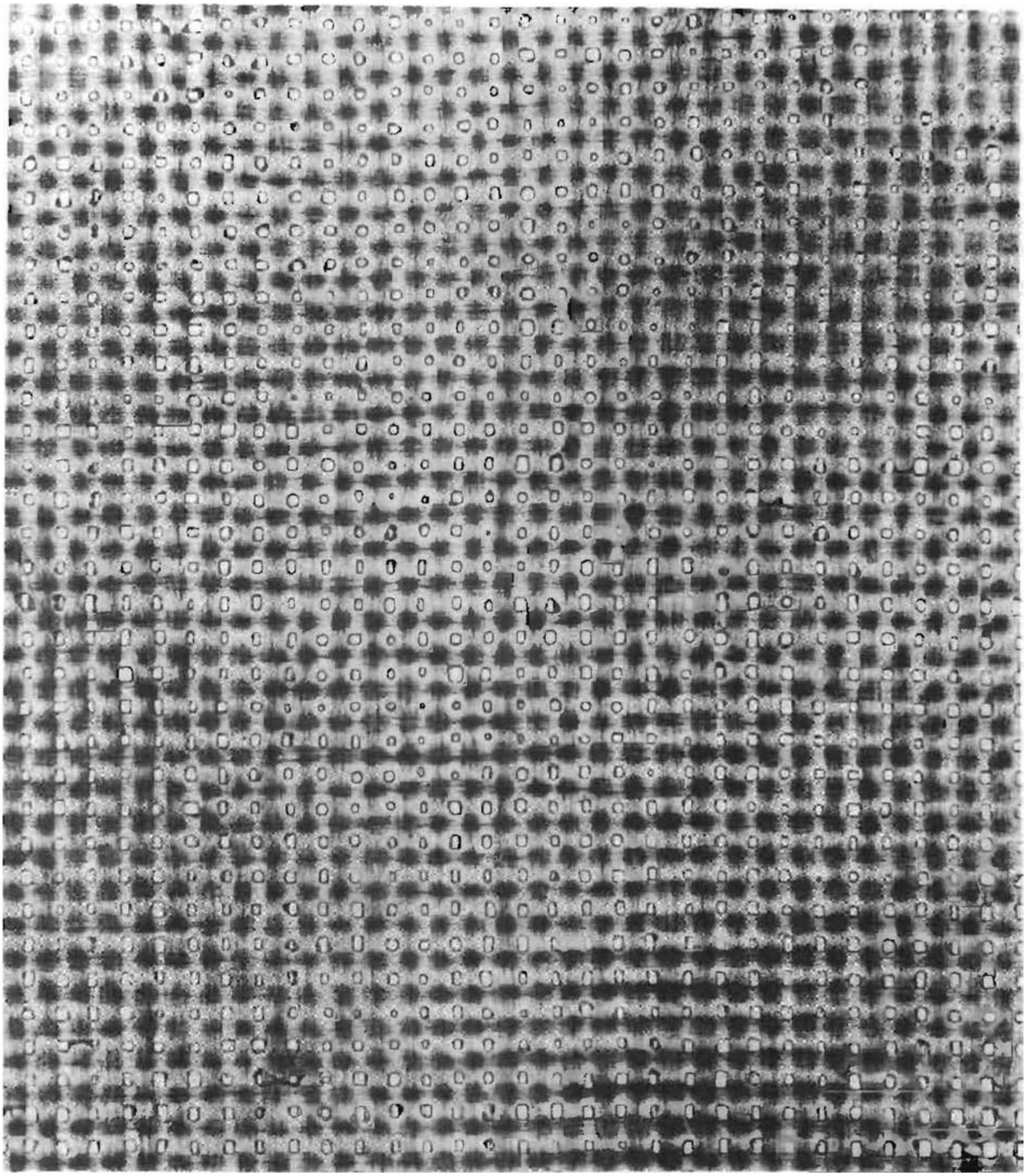


Figure 39.--Photomicrograph showing openings between weave of one sheet of glass cloth with 43 percent resin content after curing between cellophane sheets.

Z M 74086 F

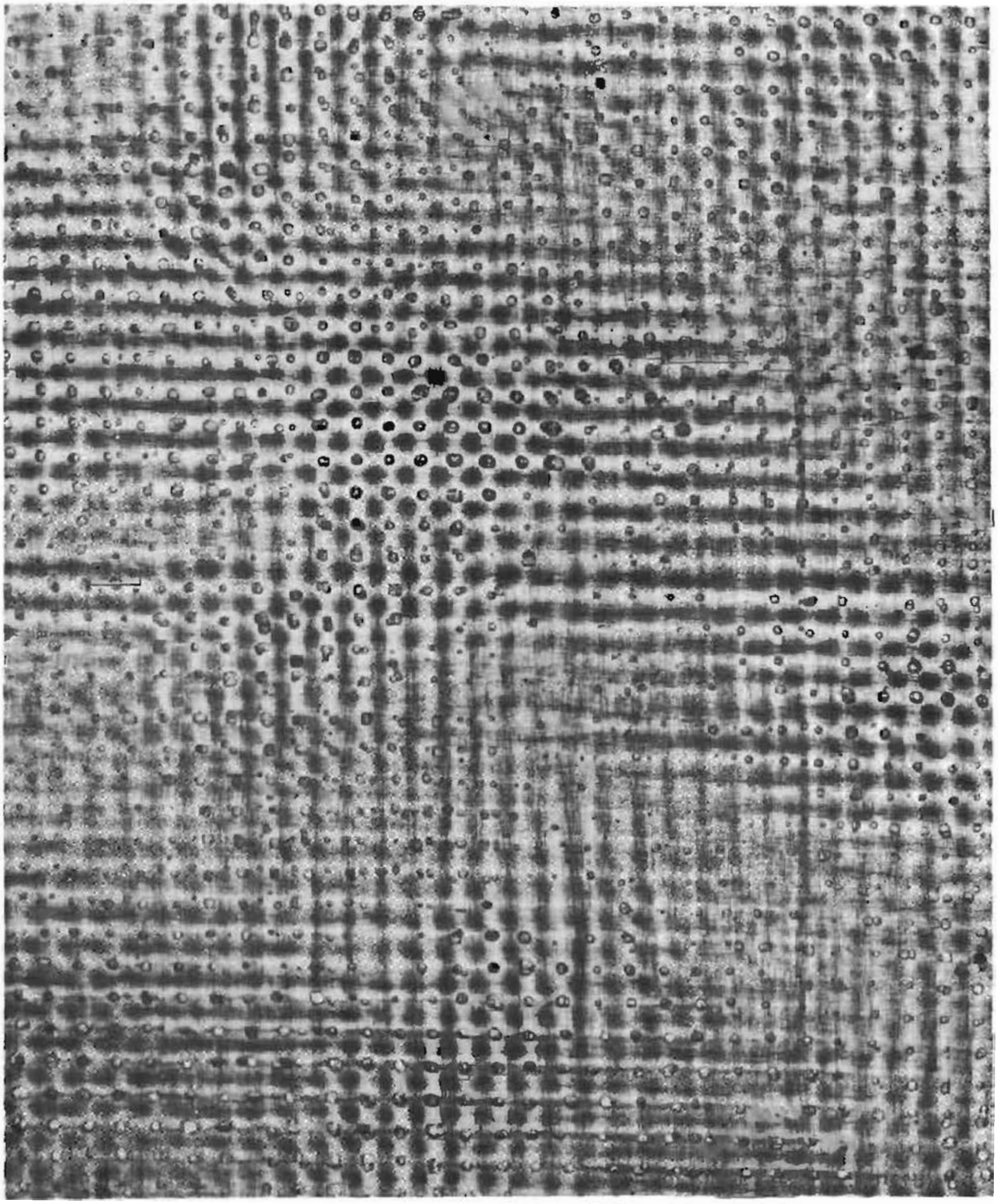


Figure 40.--Photomicrograph of three-ply glass cloth face with 43 percent resin content, after curing between sheets of cellophane, showing variation in air-bubble size depending upon register of plies.

Z M 74087 F

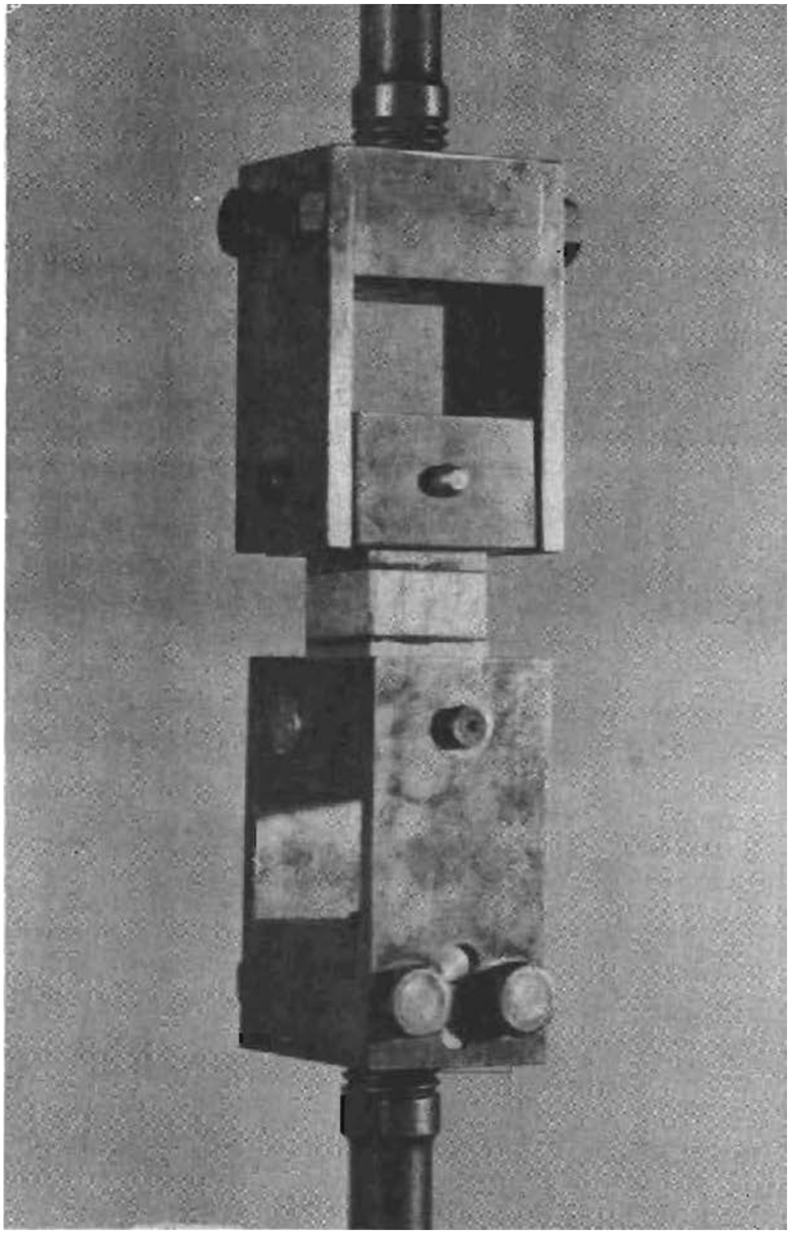


Figure 41.--Forest Products Laboratory type tension specimen for sandwich materials assembled in testing apparatus.

Z M 74088 F

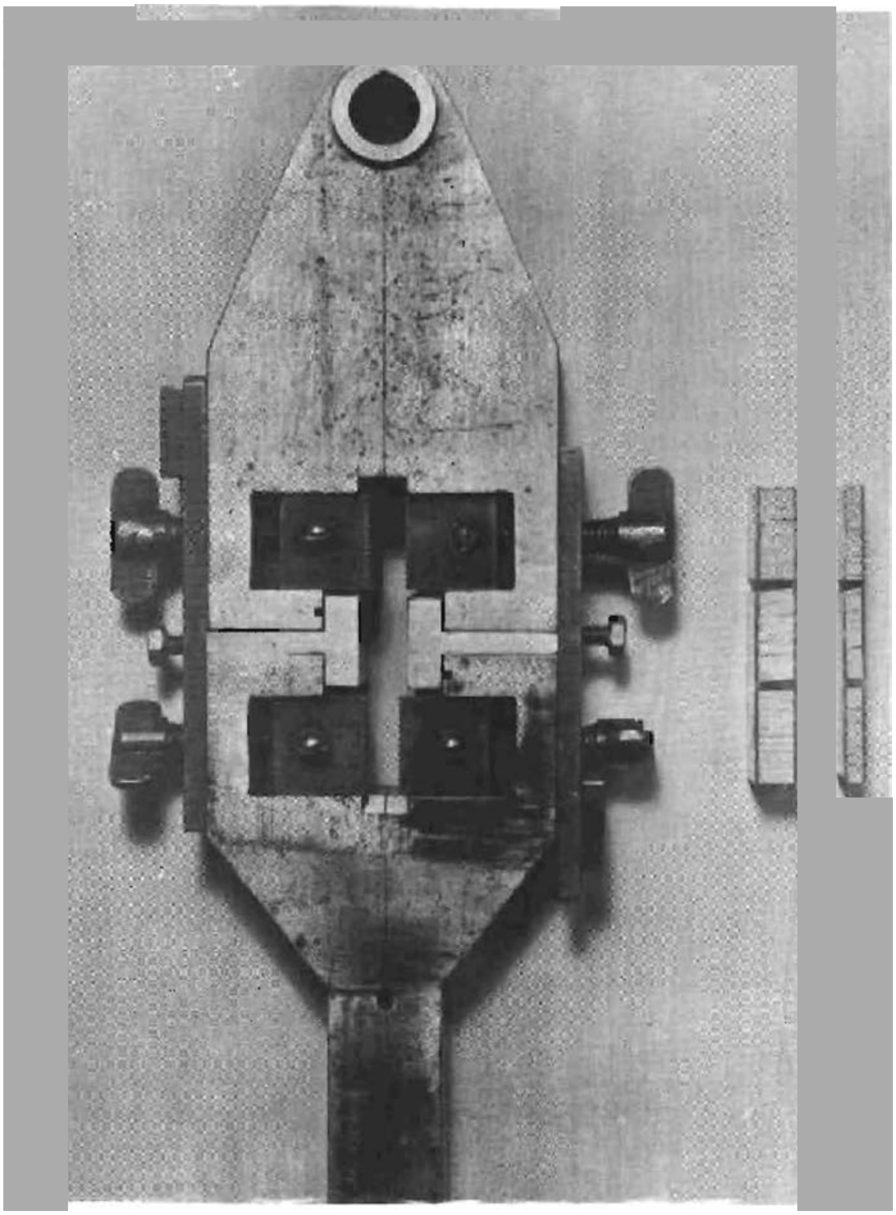


Figure 42.--Shear specimens and gripping jaws with special side-plate attachments.

Z M 74089 F

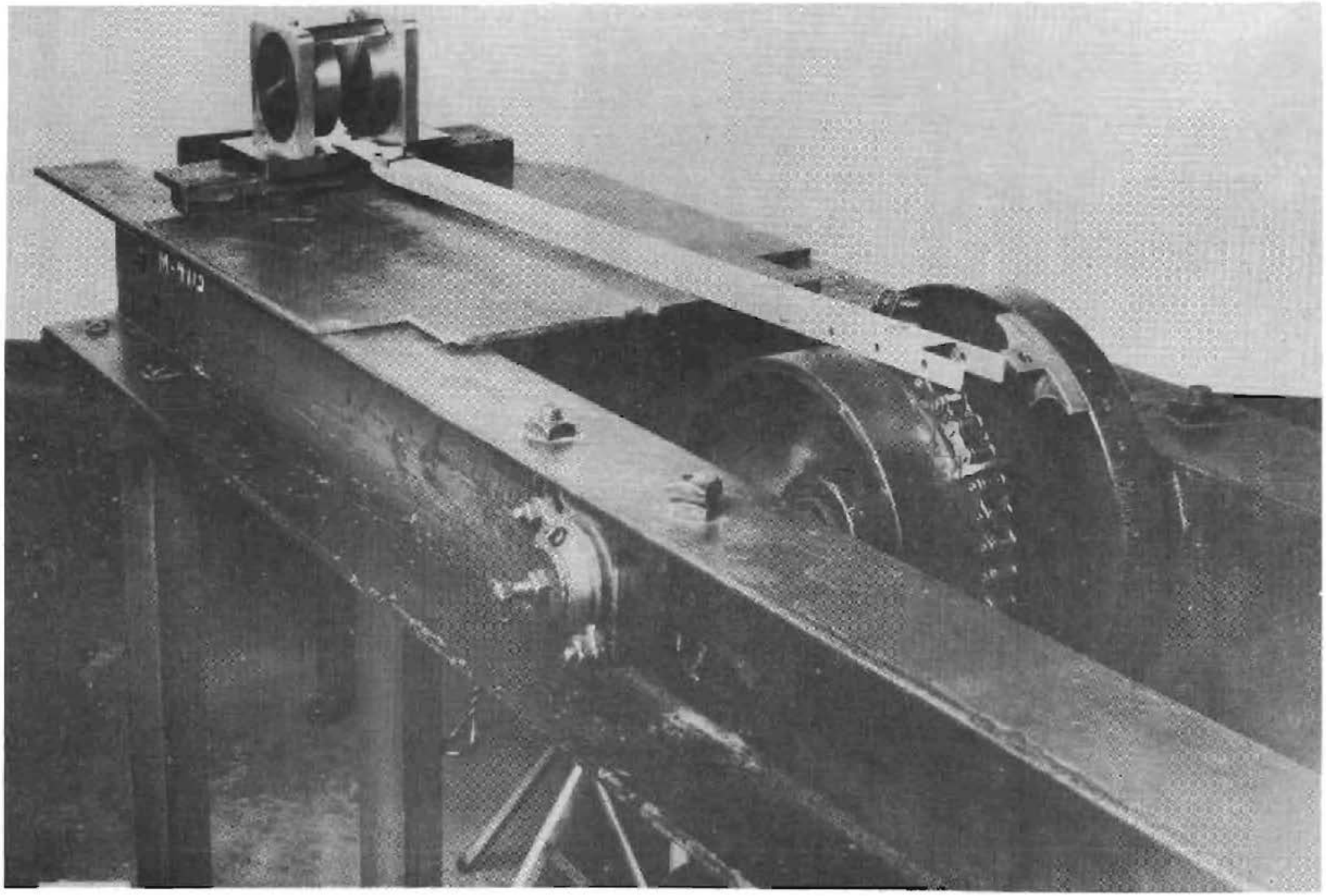


Figure 43.--A strip-test specimen after test in the Forest Products Laboratory toughness testing machine.

Z M 74090 F