PAPER HONEYCOMB CORES FOR STRUCTURAL BUILDING PANELS:

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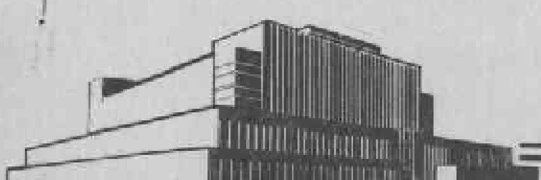

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UNITED STATES DEPARTMENT OF AGRICULTURE
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In Cooperation with the University of Wisconsin

PAPER HONEYCOMB CORES FOR STRUCTURAL BUILDING PANELS: EFFECT OF RESINS, ADHESIVES, FUNGICIDE, AND WEIGHT OF PAPER ON STRENGTH AND RESISTANCE TO DECAY[1]

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Summary

This report presents the effects of decay, acidity or alkalinity, and aging on the tensile strength of papers and on the compressive and shearing strength of cores made from different combinations of these papers, saturating resins, and adhesives. All cores were made of corrugated paper assembled so that half of the flutes were perpendicular to the facings. Base material consisted of kraft paper of 30-, 50-, and 65-pound weight and containing 5, 10, or 15 percent of phenolic resin, and phenolic, urea, or sodium silicate adhesives.

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[1] This work was undertaken and initiated in cooperation with the Housing and Home Finance Agency. Report originally dated June 1951.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

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The compressive and shearing strengths of the cores increased with an increase in resin content, particularly in the wet condition. The shearing strength was not affected to any great extent by the type of adhesive used for bonding sheets of paper together. The maximum values were obtained by placing the webs of the corrugations parallel to the spans of the specimens. The densities of the cores ranged from 1.6 to 3.0 pounds per cubic foot.

Unimpregnated paper showed a complete loss of tensile strength after exposure to decay fungi for 2 months, while a paper containing 15 percent of water-soluble phenolic resin incurred practically no loss in strength under similar exposure. Pentachlorophenol added to the impregnating resin was effective in suppressing the action of fungi on paper containing 5 percent of resin. Paper impregnated with water-soluble phenolic resin was much more resistant to decay fungi than paper containing alcohol-soluble phenolic resin. Specimens striped with sodium silicate incurred lower strength loss than specimens striped with phenolic adhesive.

Introduction

A realization some years ago of certain technical advantages of the sandwich panel stimulated research in materials and design that could put the singular virtues of sandwich construction to practical use. A great variety of facing materials such as metal, wood, hardboard, glass fiber, and plastic were bonded to a great variety of lightweight core materials such as balsa wood, rubber and plastic foams, and formed sheet materials such as cloth, metal, and paper. The cost of materials and processes varied over a wide range. Uses, real or considered, ranged from thin and small aircraft parts to unusually large and thick building panels. As the development progressed, a sharper distinction between highly specialized aircraft panels and large building panels became evident.

As the search for suitable core continued and careful consideration was given to the economics, availability, and structural and other properties of materials, it became increasingly clear that paper would play an important part in large-scale development of this industry. At an early date it was obvious that paper subjected to high moisture conditions would require resin treatment to overcome its inherent loss of strength upon wetting. It is due, indeed, to the advent of resins such as the phenolics, ureas, and melamines that paper can enter this field.

Paper has been converted to honeycomb by such methods as corrugating, expanding (as in the old-fashioned Christmas bell), or by forming it into figure-8 flute sections. This report refers to only one of several assemblies possible from corrugated paper, but the data are intended to apply generally to any paper-honeycomb structure.

In 1947, following several years of experiments with paper cores and sandwich panels at the Forest Products Laboratory, the status of the work was reviewed, and many of the most promising ideas were gathered together and crystallized in the form of a sandwich-panel test-building unit for an outdoor exposure test. A description of this unit was published in Technical Paper No. 7 of the Housing and Home Finance Agency, entitled "Physical Properties and Fabrication Details of Experimental Honeycomb-core Sandwich House Panels." Most of the core used, designed as type XN, was produced from a kraft paper of 50-pound weight, corrugated with A-size flutes, and assembled in a cross-banded form so that one-half of the flutes were perpendicular to the facings of the sandwich panel. To impart permanence, wet strength, and a degree of resistance to decay fungi, the paper was impregnated with approximately 15 percent of water-soluble phenolic resin. To assure a good bond between adjacent cross-banded sheets of corrugated paper in the core, a phenolic resin adhesive was used in an amount equal to about 10 percent of the weight of the core. The choice of this material and method of assembly represented a reasonably safe compromise of properties based on considerations of strength, thermal insulation, and facility of manufacture of sandwich panels on a commercial scale. Although the weight of paper and resin content seemed more than adequate, the conditions described above were selected so as not to jeopardize other aspects of the test. Therefore, work was begun almost immediately to determine more completely the effects of resins, adhesives, fungicides, and paper weight, with the objective of lowering costs of materials, and some of this work is herein reported. Possible economies studied were as follows:

1. Lowering the resin content.--Previous testing of physical properties of phenolic-impregnated paper had demonstrated that wet-strength values increased as the resin content was increased from 0 percent to about 25 percent. Resin content in excess of about 15 percent, however, did not seem to produce a gain in strength commensurate with the increased quantity of resin required. To explore the possibility of a further economy of resin, the properties of cores containing 5, 10, and 15 percent of resin were compared. Since a degree of resistance to decay fungi can be assumed to be due to the presence of resin in the paper, this property must be considered if the resin content is to be reduced. Resistance to decay that may be lost by a reduction of resin content, however, might be increased again by a small addition of a fungicide.

2. Reducing the weight of paper.--A kraft paper was selected for this work because it is potentially available in large tonnages at a reasonable price and because the indications of permanence of this chemical fiber are favorable.

Paper of less than 30-pound weight (3,000 square feet) was not used to make cores because it was believed that a lighter paper would aggravate problems of corrugating and handling at high production rates. It is possible that a further economy might ultimately be provided by the use of paper made of still less expensive fibers.

3. The use of less costly adhesives.--A sandwich made up of a core construction of the type described requires that the ends of each flute shall be adequately bonded to both facings with a high-quality thermosetting adhesive. On the other hand, it was hypothesized that the quality of the bond between individual sheets within the core may not be critical. The cost of thermosetting adhesives and of the equipment necessary to use an adhesive of this type are uneconomical features in the process unless the resultant high quality of bond is required. The use of a cold-setting adhesive offered a possible reduction in the amount of equipment necessary to manufacture the core material. To explore the effect of the quality of the bond between sheets of paper on the properties of a sandwich, a series of tests was made to compare (a) phenolic resin, (b) urea resin, (c) sodium silicate, and (d) no adhesive. Although the assembly of corrugated sheets in a panel without the use of a sheet-to-sheet adhesive is admittedly impractical, it was reasoned that the resultant properties would establish the lower limits of strength. A reasonable strength in a core without adhesive would permit consideration of a nonwater-resistant adhesive, such as sodium silicate. Advantages of this adhesive include rapid setting, very low cost, and, if applied in a special way, a possible improvement in fire resistance and thermal insulation. The effect of this material on such properties as decay resistance, aging, and strength of a sandwich in the wet condition requires consideration for a proper comparison of various adhesives.

A diagrammatic sketch of the variables evaluated in this report is presented in figure 1. The studies concerned materials designed for exterior structural use; for a great number of products, the use of less costly papers and resin extenders could undoubtedly effect further appreciable economies.

Preparation of Test Material

Papers, Resins, and Adhesives

A neutral kraft-base paper of 30-, 50-, or 65-pound weight (3,000 square feet) was selected for these tests. A water- or an alcohol-soluble phenolic resin of a commercial type was used as an impregnant for the paper. Three types of adhesives were used for assembly of sheets into the cores: (a) a hot-setting phenolic resin containing 6 percent of an acid catalyst, supplied at 60 percent concentration and used without further dilution; (b) a cold-setting urea resin prepared from a dry powder according to manufacturer's instructions; and (c) a typical commercial sodium silicate such as is used in fiber boxes. The silicate adhesive was obtained as a 40 percent solution and was used as received.

All sandwich panels had facings of three-ply, 3/16-inch yellow birch plywood and were bonded to the core with the hot-setting phenolic resin.

Impregnation of Paper

The paper was treated on an experimental resin-impregnating machine. Nominal water-soluble phenolic resin contents of 5 and 15 percent were obtained on the 30-pound paper, of 5, 10, and 15 percent on the 50-pound paper, and of 5 percent on the 65-pound paper. A small amount of the 50-pound paper was also impregnated with 15 percent of an alcohol-soluble phenolic resin. The resin content was based on the difference in weight between the untreated paper and the treated paper, corrected for volatile content, as it emerged from the drying tower of the impregnator, and it was expressed as a percentage of the treated weight. The temperature of the tower was about 140° C. (284° F.) at the center of the tower, and the speed of the paper through the 12-foot tower was approximately 4-1/2 feet per minute. Under these conditions the volatile content of the paper was between 3 and 6 percent. This content was based on the volatile loss during a 10-minute exposure in an oven at 160° C. (320° F.) and was expressed as a percentage of the original weight of the treated paper. In most cases the resin was diluted with a mixture of half water and half ethyl alcohol. Some alcohol was needed to avoid excessive loss of the wet strength required to carry the base paper through the impregnator. The alcohol-soluble resin was diluted with ethyl alcohol.

A few preliminary tests were made on methods of incorporating a fungicide in the paper. The simplest way to do this appeared to be to impregnate with a solution containing both resin and fungicide. A commercial grade of pentachlorophenol was selected, with which past experience indicated that an amount of about 2 percent based on the weight of the fiber was desirable. The concentration of resin solution required to obtain a 5 percent resin content was prepared, and the pentachlorophenol was added in a ratio of 2 to 5 with the resin, calculated on the solids basis. The resin diluent was a mixture of half water and half ethyl alcohol, and the required amount of pentachlorophenol was dissolved in a portion of the alcohol before being added to the solution. After the paper was dipped in the solution, it was passed through the drying tower for removal of solvent. It was not known to what extent this may have altered the ratio of resin to fungicide. The pH of the resin solution was lowered from 7.6 to 5.0 by the addition of the fungicide.

Corrugating

Rolls of the impregnated paper were corrugated on a commercial machine equipped with A-size flute rolls. Paper of 12-inch width was corrugated at the rate of 15 feet per minute with a roll temperature of approximately 165° C. (329° F.). No attempt was made to cure the resin in the corrugating rolls. The sheets were cut by hand into 4-foot lengths and were nested as they were cut. No particular difficulty was encountered with any of the papers, although the 30-pound paper with only 5 percent of resin required careful handling after it was corrugated. The 50-pound paper containing 15 percent of alcohol-soluble resin appeared to have the deepest corrugations.

Cure of the Saturating Resin and Striping Papers With Glue

Corrugated paper in packs about 3 inches thick was placed in a circulating-air type of oven at a temperature of 125° C. (257° F.) for about 4 hours. The resin was believed to be substantially cured by this treatment. Because of the subsequent use of adhesives containing water, it was believed desirable to cure the resin at this stage of the process. The increased stiffness of the flutes that resulted from this cure was an aid to subsequent handling.

In order to obtain physical properties of the impregnated papers, it was necessary to cure a number of the uncorrugated sheets. Sheets 12 inches square were subjected to 163° C. (325° F.) for 5 minutes. This was done without pressure on the platens of a hot press.

Additional sheets of uncorrugated 50-pound paper for accelerated-aging and decay tests were cured similarly, except that the curing time was reduced from 5 to 4 minutes. The time was reduced because subsequent processing of these sheets required additional heat treatment. Lines of the various adhesives were applied to sheets of the cured paper. The adhesives in each case were applied to the crests of a corrugated sheet and were transferred by impression to a 12- by 12-inch uncorrugated sheet. Sufficient adhesive was applied to the corrugated sheets so that the weight of the glue stripes on the uncorrugated sheet was about equal to that used in the manufacture of the cores. The direction of stripes was always at right angles to the machine direction of the paper. The glue stripes as they appeared on the uncorrugated sheet are shown in figure 2. After application of the adhesive, the sheets were air dried, then given an oven treatment for 2 hours at 80° C. (176° F.), after which they were further heated for 5 minutes at 125° C. (257° F.) between the platens of a hot press. This procedure was selected to afford conditions that would cure each adhesive, minimize difficulties due to running or blistering of the adhesive, and still maintain conditions that were uniform for all papers and similar to conditions used to cure the cores. Considerable difficulty was experienced because of curling of the striped papers; in the case of the silicate adhesive it was necessary to humidify the papers to remove the curl without cracking the paper.

Bonding of Corrugated Paper and Curing of Core

The various adhesives were applied to the crests of the corrugated sheets by a small, hand-driven glue spreader, illustrated in figure 3. The phenolic adhesive was used as received, at 60 percent solids content, and the spread was adjusted to give an application of about 1.2 grams of solid adhesive per square foot of corrugated paper. The dry urea resin was mixed with water and applied at the rate of about 1.5 grams of solid adhesive per square foot. The silicate was used as received, at about 40 percent solids content, and spread at a rate of about 2.4 grams of solids per square foot. The phenolic adhesive did not penetrate far into the paper, and therefore a lesser amount was required. This small penetration was probably due to the nonaqueous nature of the adhesive solvent. A greater degree of penetration resulted when the urea or silicate adhesives were used; the swelling effect of the silicate was enough to cause distortion of the flutes in papers containing 5 percent of resin. The sheets of corrugated paper were passed through the glue spreader with the flute direction parallel to the axis of the spreader roll. Core blocks of 1 by 4 feet by about 3 inches in thickness were assembled for each of the combinations of paper, resin content, and adhesives. All cores were of the XN type of construction, that is, with the flutes of alternate sheets at right angles (fig. 4). As the flute direction of a 1- by 4-foot sheet was in the short dimension, it was necessary to cut one-half of the sheets into shorter segments to produce a cross-laminated core of this size. The short segments were butt-joined, and the joints were staggered throughout the thickness of the core. Plywood cauls were placed on both sides of each core to assure good crest contact.

The adhesive in the core blocks bonded with phenolic resin was cured in a circulating-air oven for 4 hours at 125° C. (257° F.). Although the cores bonded with urea and silicate did not require this additional heating to set these adhesives, they were given a similar exposure to maintain uniformity of treatment. The core blocks were then ready for sawing.

Fabrication of Sandwich Panels

The core blocks were cut in the long direction with a circular saw. The cut segments were edge-bonded to produce core sections 1 by 22 by 16 inches in size for panels to be tested in bending and 12 by 12 by 2-5/8 inches in size for panels to be tested in compression. Facings of three-ply, 3/16-inch birch plywood were bonded to cores with a phenolic adhesive spread to approximately 25 grams per square foot (one part on core and two parts on facing). The cores were used in the sandwich so that one-half of the flutes were perpendicular to the facings. For panels to be tested in bending, the facings and the core were assembled so that the grain direction of the outer veneer was parallel to the span of the test specimen. Panels were pressed under a pressure of about 15 pounds per square inch at a temperature of 115° C. (239° F.) for 40 minutes and were removed from the press without cooling.

It was necessary to develop a special technique for the assembly of the core, which was to be made without the use of a crest-bonding adhesive. As a core assembly without an adhesive could not be sawed to desired thickness, it was necessary to precut the strips of corrugated paper to the width desired for the sandwich. The flutes in one-half of the strips were in the short direction. The strips were assembled in the jig shown in figure 5. The channels of the jig were designed to extend beyond the platens of the press and yet to hold the strips in place until the facings had been bonded to the edges of the strips. The channels of the jig were finally removed by sawing.

Methods of Test

Physical Properties of Paper

Weight, thickness, density, wet and dry tensile strength, and ring crush tests of impregnated and unimpregnated papers were obtained according to the standard method of the Technical Association of the Pulp and Paper Industry.

pH-Value Tests

Determinations of pH values were made on solutions of resins, impregnated papers, and sections of core material. In addition, sections of core material were dissected to isolate either glue-line area or paper between glue lines. The procedure used on papers corresponds to TAPPI Standard Methods No. T435M-42. This consists essentially of a hot extraction using a standard amount of material and distilled water. Measurements were made on a Beckman pH meter.

Accelerated-Aging Tests

Specimens of paper 15 millimeters by 4 inches in size, with and without glue stripes, were cut so that the grain direction of the paper was placed parallel to the long dimension of the specimen. Specimens were placed in a covered chamber and exposed to steam at 98° C. (208° F.) for 72 hours. After being reconditioned in an atmosphere at 50 percent relative humidity and 75° F., the specimens were tested for tensile strength and the values were compared with unexposed control samples. Tensile strength was determined by the TAPPI method.

Decay Tests

Specimens of paper 15 millimeters by 4 inches in size were cut from the 50-pound papers, either with or without glue stripes. The machine direction of the paper was parallel to the long dimension. Specimens of completed honeycomb core 1/2 by 1 by 3 inches were also prepared for decay tests. These were sawed from each block of core material made from the 50-pound paper. Each specimen was seven plies wide, and the web of the corrugation was parallel to the long dimension.

The wood-destroying fungi used were: Madison No. 517, a white-rot fungus that attacks lignin predominantly and leaves the specimen white and sponge-like; and Madison No. 617, _Lenzites trabea,_ a brown-rot fungus that attacks the cellulose and leaves the specimen brown and crumbly. The former was selected because earlier laboratory experience showed it was fairly tolerant to pentachlorophenol, a fungicide that was used in treating some of the test specimens. The latter was chosen on the basis of results from a brief exploratory test of resin-impregnated paper exposed to fungi on soil cultures; it was tolerant to pentachlorophenol and caused considerable deterioration to control specimens.

The fungi were grown on a substrate of 25 cubic centimeters of malt agar (Trommer's malt extract, 25 grams; bacto-agar, 20 grams; and distilled water, 1,000 cubic centimeters) in 6-ounce French-square bottles placed horizontally. The test specimens were placed directly on the fungus mat, as shown in figure 6.

The decay test procedure was as follows:

1. All test and reference specimens were conditioned in an atmosphere of 75° F. and 50 percent relative humidity for at least 2 weeks until an approximate equilibrium weight was reached, when the weights of the specimens were recorded.

2. The test and reference specimens were surface-disinfected by placing them in glass bottles and autoclaving them for 30 minutes at atmospheric pressure.

3. The test specimens were placed in bottles containing vigorous cultures of the fungi. The reference specimens were placed over sterile agar in bottles. All culture bottles were incubated at about 80° F. and in a relative humidity of about 70 percent.

4. The cultures were examined several times to observe and record the growth of the fungi, presence of contaminants, etc., during the 2-month period of the test. The specimens were then removed from the bottles and freed of mycelium as completely as possible. Readings of pH were made of a number of the substrates remaining in the bottles, and isolations of the fungi were attempted from some of the cultures, especially those that had contained pentachlorophenol-treated paper.

5. The test and reference specimens were returned to conditions of 75° F. and 50 percent relative humidity for about 2 weeks, after which a few of the strip specimens were weighed and all were tested for tensile strength. The core specimens were weighed at the end of 3 weeks of conditioning.

6. Computations were made of the percentage change in weight of the core specimens, based on the approximate equilibrium weights at 75° F. and 50 percent relative humidity before and after exposure.

Shearing Strength Tests

The sandwich panels were cut into specimens 2 by 20 by 1-3/8 inches in size. Specimens were prepared with the webs of the corrugation parallel to the spans. In some cases, particularly with respect to silicate adhesive, specimens were also prepared with the webs of the corrugations perpendicular to the spans. At least six specimens were cut to represent each variable. Half were tested wet after soaking in water for 48 hours, and half were tested after conditioning in an atmosphere of 65 percent relative humidity at 75° F. The specimens were tested under a load applied at the center of an 18-inch span. The load was applied at a convenient rate until failure occurred. Central deflections were measured. The arrangement of apparatus is shown in figure 7.

Compression Strength Tests

Sandwich panels 3 inches thick, representing the same construction as was used for shearing tests, were sawed into compression test specimens 2 by 2 inches in cross section. These specimens were compressed in a direction normal to the facings. They were tested either after they had been conditioned in an atmosphere of 65 percent relative humidity at 75° F. or in the wet condition after they had been soaked in water for 48 hours.

Discussion of Results

Properties of Papers

The effect of resin impregnation on the physical properties of the paper was reflected chiefly in a greatly increased tensile strength of the paper when wet. Data obtained on the impregnated and unimpregnated papers are given in table 1. Figure 8 shows the effect of resin content on the dry and on the wet tensile strength of the 50-pound kraft paper tested in the direction of paper grain (machine direction). The greatest increase in wet tensile strength was obtained from the first 5 percent of resin. The wet tensile strength in the machine direction increased from 3 to 30 pounds per inch of width with a 5 percent resin addition and up to 40 pounds per inch of width for a total resin content of 15 percent. The comparable increase in dry strength was from 35 to 42 pounds with 5 percent resin to 50 pounds per inch of width with 15 percent resin. The wet tensile strength of the 50-pound paper containing 15 percent resin was greater than the dry strength of the paper containing no resin.

A comparison of the use of water-soluble resin and alcohol-soluble resin saturants indicated that the wet tensile strength of the paper impregnated with a water-soluble resin was greater than that obtained from a paper containing an equal amount of alcohol-soluble resin, although the tensile properties of these papers when dry indicated the opposite to be true. It should be emphasized that the analysis of strength was based on pounds per inch of width; it was recognized that strength values expressed in pounds per square inch would be considerably different. Paper impregnated with a water-soluble resin had a higher ring crush value than did papers containing an alcohol-soluble resin tested in the wet condition. It was observed that the paper containing alcohol-soluble resin was less brittle. The type of tensile failure for wet specimens representing each resin is shown in figure 9. The fibrous nature of the paper break in the case of the alcohol-soluble resin was no doubt caused in part by the less thorough impregnation of the fibers because of the larger molecular size of the resin and its nonaqueous solution. It was interesting to note the relative swelling in thickness due to impregnation; for example, passing the 50-pound paper through a water-soluble resin increased the thickness from 4.3 to 6.0 mils, while the use of alcohol-soluble resin yielded a thickness value of 4.7 mils. Resin was more visible on the surface of the sheet containing alcohol-soluble resin. For papers with various amounts of water-soluble phenolic resin, the relationship of resin content to thickness was approximately linear.

The addition of 2 percent of pentachlorophenol to the saturating resin had no significant effect on the tensile strength of the paper and apparently had no unfavorable effect on the cure of the resin.

pH Value of the Core Material

The fabrication of core material consisted of the combination of a neutral paper with saturating resins and adhesives having different degrees of acidity or alkalinity and used in various proportions. Thus, the pH value of the completed core was likely to reflect the composite effect of the materials used. The final pH value of the core was considered to be important, and it undoubtedly bears a relation to the aging characteristics of the material. Specific data on a satisfactory pH value for optimum permanence of a core are lacking, but it appeared reasonable that this value should be as near the neutral point of 7.0 as is practicable.

Data on pH values are given in table 2 and figure 10. The pH values of the core ranged from 5.4 to 10.4, depending on the amount of saturating resin and the type of adhesive. A core made with 15 percent resin paper and bonded with acid-catalyzed phenolic adhesive yielded a pH value of 7.2. By reducing the resin content of the paper to 5 percent, the pH value was reduced to 5.6 because of a greater ratio of acid-catalyzed adhesive to alkali-catalyzed saturating resin. For the 15 percent resin paper, the pH value of the core was 10.2 for a silicate adhesive and 7.6 for a urea adhesive. The sodium silicate appeared to control the pH value of the core to a greater extent than the phenolic adhesive, possibly because of a buffering action. This is illustrated in figure 10, which shows the pH value of a silicate-bonded core to be about 10.3 for paper of both 5 and 15 percent resin. The 5 percent resin paper bonded with phenolic adhesive had a pH value of 5.6; this was further reduced to 5.4 by the use of 2 percent of pentachlorophenol as a fungicide.

Because the pH value of an assembled core reflects the average, it may not be a good indication of concentration of acid or alkali at various points in a core, particularly at the areas surrounding the glue line. All cores were therefore dissected to yield samples representing (a) glue-line area and

(b) paper between glue lines. A typical example of values obtained is given in figure 11 for the 50-pound paper containing 15 percent of saturating resin and bonded with acid-catalyzed phenolic adhesive. The area including the glue lines, of course, had a greater acidity than the paper between glue lines, but the pH of the final core was nearly at the neutral point of 7.0. When a sodium silicate adhesive was used, the pH value of the glue line was approximately the same as the pH value of the entire core.

Accelerated Aging

In addition to pH measurements, it was believed that a simultaneous exposure of papers to heat and moisture would give a useful indication of strength losses that might occur over a long period of time. Although an untreated neutral kraft paper was believed to have favorable aging characteristics, the possible deleterious effect of resin treatment or of adhesive introduced by this combination required further study. For this purpose an exposure to steam for 72 hours was selected. Tensile specimens were exposed and tested to obtain an index of the damaging effects, although it was recognized that tensile strength was not a primary factor in a sandwich core of this type. Specimens with glue stripes were included to detect possible effects at the line of contact between the paper and adhesive.

In general, no great loss of tensile strength for any combination of saturating resin and adhesive was apparent from this exposure, as shown in table 3. For a series of 50-pound papers containing about 15 percent of saturating resin, the loss in tensile strength on papers striped with phenolic, urea, and silicate adhesives was 4, 12, and 6 percent, respectively. This relationship between phenolic and silicate adhesives was not substantiated by the 5 percent resin content paper. No loss of strength was observed on unstriped papers containing pentachlorophenol, but when this paper was striped with phenolic adhesive a loss of 18 percent occurred. The latter sample had a pH value of 5.4, which was the lowest of the series. However, no correlation between pH value and the strength loss due to this exposure was evident.

Decay Resistance

The influence of the amount and type of saturating resin on the decay resistance of kraft paper exposed to decay fungi for 2 months is given in table 4. Unimpregnated kraft paper showed a complete loss in tensile strength after exposure to the two types of fungi. A 5 percent water-soluble phenolic resin paper without glue stripes lost on the average about 35 percent of its strength under the same conditions (fig. 12). Negligible losses in strength resulted with a 15 percent water-soluble resin impregnation and also when 2 percent of pentachlorophenol was added to the 5 percent resin paper.

In contrast to the effectiveness of the 15 percent water-soluble resin treatment, the use of 15 percent of alcohol-soluble resin resulted in a product that lost more than 90 percent of its strength after the 2-month exposure. Growth of fungus No. 517 over the surfaces of the alcohol-soluble resin specimens was nominal at the end of 1 month, but it increased greatly during the second month. Only a slight difference in growth over the surfaces of the water-soluble resin paper specimens was observed between the first and second months. The superior decay resistance of the water-soluble resin paper can probably be attributed to the fact that the fiber cell wall was more thoroughly saturated because of the presence of water in the solvent and of the smaller molecular size of the resin. The alcohol-soluble resin gave a varnishing effect to the sheet, which may have accounted for the temporary protection against fungus action.

Some evidence of the loss in strength due to decay was obtainable by visual inspection of the specimens. The specimens of untreated paper and paper treated with 15 percent of water-soluble phenolic resin without glue stripes and exposed to fungus No. 617 are shown pictorially in figures 13 and 14, respectively.

Specimens of resin-treated paper having phenolic glue stripes were less resistant to fungus No. 617 than specimens without glue stripes, but this effect was not so evident for specimens exposed to fungus No. 517. Specimens striped with silicate adhesive were considerably more resistant to decay fungi than unstriped paper. For example, a paper with 5 percent of water-soluble resin exposed to both fungi sustained an average loss of strength of 66 percent with the use of phenolic glue stripes, as compared with a loss of strength of 5 percent with the silicate adhesive and 35 percent with no adhesive. No reason is given for the apparent effectiveness of the sodium silicate, although it may be related to the alkalinity induced by the silicate. The difference in strength between silicate glue stripes and no glue stripe used with 15 percent resin content paper, however, was negligible. Since the 15 percent water-soluble resin paper itself is adequately resistant to decay fungi, it appears from these results that the choice of the bonding adhesive is not critical for use with this paper, but that it does become important in the lower range of resin content.

Small segments of assembled core were exposed to fungi for the purpose of obtaining an evaluation of the material as used in sandwich panels. It was hoped that actual loss in shear strength due to decay fungi might be determined, but since this was not practical, the evaluation was restricted to visual inspection and weight loss on phenolic-bonded cores. From the results obtained on core specimens and strips of paper bearing glue lines, it was concluded that strip specimens tested for loss in tensile strength afforded a more practical method for evaluating the effect of fungi on paper.

Some of the core specimens proved to be very difficult to handle, and the results obtained from their use were not so satisfactory as the results obtained on strip specimens. The initial weights were low and, during the test, small bits were observed to flake off or to adhere to the agar in the bottles. It was also very difficult to remove the mycelium completely. In the case of the cores bonded with silicate, the results of weight loss were discarded since, in addition to the above difficulties, many of the specimens came apart and a considerable amount of the adhesive diffused away from the specimens because of high moisture in the test bottle. The changes in weight of the phenolic-bonded core specimens during the course of the test are shown in table 5. The consequential losses recorded occurred in the specimens prepared from 5 percent water-soluble resin and 15 percent alcohol-soluble resin, as was the case with the strip specimens.

Both fungi used in the test produced growth over at least some portion of all striped specimens except those containing pentachlorophenol. There was no particular relationship between or within fungi on the amount of fungus coverage and the loss in tensile strength of the specimens. For example, the growth of fungus No. 617 was abundant on silicate-striped specimens, yet there was little loss in tensile strength of the paper. The observations helped establish whether conditions were satisfactory for the growth of the fungi and hence whether the specimens were properly exposed to attack.

Only one of the cultures on which the strip-test specimens were placed became contaminated. This contamination seemed to have no adverse effect upon the results. Several of the reference specimens placed over sterile agar, however, became contaminated with bacteria. Again, there seemed to be no loss in tensile strength of the affected specimens, even in those having stripes of silicate adhesive, which might have produced a more favorable pH value for growth of bacteria.

At the end of the test, isolations of the fungi from those culture bottles containing specimens treated with pentachlorophenol were attempted. None of the isolations of fungus No. 617 grew, but those of No. 517 grew in 9 of 16 cultures. Thus, this fungus was able to remain viable during the course of the test, although it was not able to grow over or to deteriorate the treated specimens.

The pH values were obtained on the substrate from some of the test bottles, and the values obtained ranged from 4.3 to 7.4. The silicate-striped specimens raised the pH value of sterile agar considerably and probably influenced the fungus cultures somewhat, but there is no evidence that this increase toward alkalinity was significant.

The loss in tensile strength of the strip specimens was generally related to their apparent deterioration. In contrast, the specimens containing pentachlorophenol appeared bright and clear. The adhesive of the silicate-striped specimens appeared to diffuse into the substrate where it was in contact, and left a reddish residue; where it was raised above the substrate, it appeared milky in color. The core specimens bonded with silicate adhesive turned dark when placed in test; most of them delaminated during exposure or subsequent handling.

Strength of Sandwich Panels

Testing of sandwich panels was confined to the determination of two properties only, shearing strength and compressive strength. Most of the bending specimens prepared to determine shearing strengths had the webs of the corrugations parallel to spans. In order to investigate the effect of the bond between the sheets of paper in the core, however, it was necessary to test several specimens having the webs of the corrugations perpendicular to the spans. For comparison of the effects of the variables, the core made from 50-pound paper containing 15 percent of water-soluble resin and bonded with phenolic adhesive was considered to be the reference standard. To simplify an analysis of the data on strength properties, the test panels were identified by a code given in table 6. Observed effects of selected variables on strength are given in tables 7, 8, 9, and 10.

Increasing the saturating-resin content of the paper increased the shearing and the compressive strength in both the dry and the wet condition and for phenolic and silicate core adhesives (table 7). The increase in strength with increasing resin content for 50-pound paper is illustrated graphically in figure 15. In the case of a phenolic-resin-bonded core, increasing the resin content from 5 to 15 percent increased the dry shearing strength about 40 percent, while the corresponding increase in the wet condition was about threefold. At 15 percent resin content, the shear stress developed in bending of the wet panels was approximately one-half that of the dry panels. For the silicate adhesive, the trends and order of strength values were approximately the same for changes in resin content, although the increase was slightly greater in the dry condition and slightly less in the wet condition than for the phenolic adhesive. The effect of resin content on compressive strength of wet panels was not so great as that obtained in shear.

As the weight of the paper containing 5 percent of resin was increased, the shear stress developed in bending and the compressive strength of the dry sandwich panels increased considerably, although no significant corresponding increase was noted on panels tested in the wet condition. For example, increasing the weight from 30 to 50 pounds increased the dry shear strength from 28 to 52 pounds per square inch for a phenolic-resin-bonded core, although the strength of corresponding specimens tested when wet remained virtually unchanged. The weight-strength relationship is shown in figure 16. For paper containing 15 percent of resin, however, the wet shear strength was more than doubled by increasing the weight from 30 to 50 pounds (table 8). The increase in wet compressive strength was not so great. No reason is apparent for the differences in trends observed for the 5 and 15 percent papers tested when wet.

For sandwich panels in which the web of the corrugation was parallel to the span, the nature of the crest adhesive appeared to have only a slight effect on the shear strength of panels tested in either the dry or the wet condition. A panel made without a crest bonding adhesive had shear strength of 63 pounds per square inch when dry and 28 pounds per square inch when wet, as compared to values of 74 and 33 pounds per square inch for a phenolic bonding adhesive (table 9). In the case of a silicate adhesive, the dry strength was slightly higher and the wet strength slightly lower than obtained from the phenolic bonding adhesive. For specimens in which the web of the corrugations was at right angles to the span, the use of a nonwater-resistant adhesive resulted in a significant loss of strength. In one case the strength dropped from 12 to 6 pounds per square inch. From these results it is evident that the web of the corrugation should be parallel to the span to obtain the maximum strength, regardless of adhesive used.

The use of an alcohol-soluble resin as a saturant resulted in a slightly higher shear stress developed in bending and in compressive strength for dry panels but lower strength for panels tested wet. Pentachlorophenol used as a fungicide did not affect the strength of the sandwich panel, as shown in table 10.

The effect of resin type and fungicide on decay resistance has been discussed previously in this report.

As a possible further economy in materials, a type of core construction was prepared from 50-pound paper with 15 percent resin content and from 30- pound paper with 5 percent of resin. It was assembled so that the flutes of the 50-pound paper were perpendicular to the facings and the 30-pound paper was used as cross plies. This core had a density of 2.1 pounds per cubic foot as compared to 2.6 pounds per cubic foot for a core made entirely from 50-pound paper with 15 percent of resin. Only a slight decrease in compressive strength or in shear strength developed in bending resulted from the use of this composite construction.

Density of Core Material

In this investigation the densities of the various cores were considered for reasons of economy, since density is a measure of the weight of ingredients required to produce a given volume of core. The cores described in this report varied in density from about 1.6 to 3.0 pounds per cubic foot, and each density represents the composite of a blend of fiber, resin, and adhesive. The proportions of material used in the cores made with phenolic crest adhesive are illustrated in figure 17. The core made from 50-pound paper containing 15 percent of water-soluble phenolic resin had a density of 2.58 pounds per cubic foot on an air-dry basis. One cubic foot of this core required about 1.97 pounds of fiber, 0.35 pound of resin saturant, and 0.26 pound of phenolic adhesive. This amount of adhesive is equivalent to a spread of 1.2 grams (solid) per square foot of corrugated paper, and the amount required is not likely to be greatly dependent upon the weight of the paper. However, a change in paper weight will affect the amount of saturating resin. Since tests on wet sandwich panels indicated that no great loss of strength was attributable to the use of nonwater-resistant crest adhesives, it appears from figure 17 that a disproportionate amount of phenolic resin was used for crest bonding and that this amount of resin could serve a more useful purpose if used as saturating resin.

Conclusions

The following general conclusions are drawn from the data obtained under the conditions described:

1. The use of phenolic saturating resin in kraft paper resulted in an increase in tensile strength in pounds per inch of width in both the dry and the wet conditions, particularly the latter.

2. Increasing the phenolic saturating resin content increased the pH value of phenolic-bonded cores. The use of sodium silicate adhesive resulted in a consistently high pH value regardless of saturating resin content. The pH value of the 15 percent resin content paper bonded with phenolic adhesive was approximately at the neutral point.

3. Exposure to steam for 72 hours resulted in small reductions in the tensile strength of paper. The difference in loss of strength between different adhesives and between paper with and without glue stripes is probably not significant.

4. Unimpregnated paper showed a complete loss of tensile strength after exposure to decay fungi. Increasing the resin content increased decay resistance; a paper with 5 percent of water-soluble resin lost more than one-third of its strength, but the loss with paper containing 15 percent of resin was negligible. Addition of 2 percent of pentachlorophenol to the impregnating resin for paper containing 5 percent of resin resulted in fungus protection. Paper impregnated with water-soluble phenolic resin was much more resistant to decay fungi than paper containing alcohol-soluble resin. The use of sodium silicate as an adhesive afforded additional protection against fungus action. Since the paper with 15 percent of resin is adequately resistant to decay fungi, the choice of bonding adhesive is apparently not critical for use with this paper; it does, however, become important in the lower range of resin content.

5. Tests on sandwich specimens showed that increases in the saturating resin content of the paper increased the compressive strength and the shear strength in bending in both the dry and the wet condition. The wet shearing strength was increased threefold for an increase of resin content of 5 to 15 percent.

The weight of the paper had no effect on the wet strength of specimens having 5 percent of resin, but considerable effect was noted for cores having 15 percent of resin.

The strengths of core specimens bonded with sodium silicate adhesive were slightly higher when dry and slightly lower when wet than corresponding values obtained from specimens having cores bonded with phenolic adhesive.

The strengths of panels having cores constructed without the use of a crest adhesive were slightly lower than those of panels having cores constructed with a crest-to-crest adhesive, a fact that indicates that high-quality bonding between individual sheets in cores is not essential.

Maximum strength, regardless of adhesive, was obtained by placing the web of the corrugated paper parallel, not perpendicular, to the span of the shearing specimen.

Table 1.--Results of physical tests made on impregnated and unimpregnated papers

Nominal paper weight (3,000 sq. ft.)	Type of phenolic resin (alcohol- or water-soluble)	Resin content	Paper weight (3,000 sq. ft.)	Thickness	Density	Tensile strength: Dry: Machine direction	Tensile strength: Dry: Cross direction	Tensile strength: Wet: Machine direction	Tensile strength: Wet: Cross direction	Ring crush tests: Parallel: Dry	Ring crush tests: Parallel: Wet	Ring crush tests: Perpendicular: Dry	Ring crush tests: Perpendicular: Wet
Lb.		Percent	Lb.	Mils	Gm. per cc.	Lb. per in. width	Lb. per in. width	Lb. per in. width	Lb. per in. width	Lb.	Lb.	Lb.	Lb.
30	....	....	30.5	2.9	0.59	26	13	2	1	....	....	....	...
30	W.S.	5	33.6	3.3	.57	31	16	22	11	....	....	....	...
30	...do....	15	37.2	3.7	.55	28	15	26	12	....	....	....	...
50	....	....	51.2	4.3	.68	35	27	3	2	9	....	7	...
50	W.S.	5	54.5	5.1	.60	42	30	30	21	....	....	....	...
50	W.S. + penta-chloro-phenol	5 + 2	56.5	5.2	.61	40	31	35	20	....	....	....	...
50	W.S.	10	57.0	5.3	.60	41	27	35	22	....	....	....	...
50	...do....	15	63.5	6.0	.60	50	30	40	28	26	15	20	11
50	A.S.	15	62.5	4.7	.75	51	40	39	22	22	12	21	8
65	....	....	66.2	5.1	.72	49	34	4	3	....	....	....	...
	W.S.	5	69.6	6.3	.61	47	35	40	24	....	....	....	...

Table 2.--Results of pH determinations made on resin-treated papers and honeycomb cores

Phenolic resin type (alcohol- or water-soluble)	Resin content	Bonding adhesive	pH value[1]			
			Paper before bonding into core	Core		
				Paper between glue lines	Assembled core	Glue-line area
	Percent					
W.S.	5	....	7.7	....	....	....
Do.........	5	Phenolic	....	7.8	5.6	4.5
Do.........	5	Silicate	....	8.1	10.4	10.7
W.S. + penta-chlorophenol	5 + 2	....	6.0	....	....	....
Do.........	5 + 2	Phenolic	....	5.7	5.4	4.9
W.S.	15	....	8.0	....	....	....
Do.........	15	Phenolic	....	7.9	7.2	4.7
Do.........	15	Urea	....	7.9	7.6	7.4
Do.........	15	Silicate	....	8.4	10.2	10.7
A.S.	15	....	7.9	....	....	....
Do.........	15	Phenolic	....	7.6	6.2	4.9

[1] Each value represents the average of two specimens.

Table 3.--Tensile strength of resin-treated papers with and without glue stripes after accelerated-aging tests

Resin[1] content	Glue line	Dry tensile strength in machine direction[2]		
		Before exposure	After exposure	Loss in strength due to aging
Percent		Lb. per in. width	Lb. per in. width	Percent
5	....	38	36	5
5	Phenolic	47	41	12
5	Silicate	48	45	7
[3]5 + 2	....	49	50	[4]3
[3]5 + 2	Phenolic	50	41	18
15	....	50	47	6
15	Phenolic	46	44	4
15	Urea	47	42	12
15	Silicate	46	44	6

[1] The saturating resin was a water-soluble phenolic resin.

[2] Each value represents the average of 10 specimens.

[3] Two percent of pentachlorophenol added to paper.

[4] This value represents a gain in strength.

Table 4.--Effect of resin content and bonding adhesive on loss of tensile strength of specimens exposed to decay fungi

Type of saturating resins	Resin content	Glue stripes	Loss of tensile strength[1]		
			Fungus No. 617	Fungus No. 517	Average
	Percent		Percent	Percent	Percent
Untreated paper	....	....	100	100	100
Water soluble	5	....	37	33	35
Do	5	Phenolic	89	43	66
Do	5	Silicate	9	2	5
Water soluble + pentachlorophenol	5 + 2	....	2	[2]2	0
Do	5 + 2	Phenolic	0	0	0
Water soluble	10	....	19	21	20
Do	10	Phenolic	63	14	38
Do	10	Silicate	[2]1	5	2
Do	15	....	6	[2]1	2
Do	15	Phenolic	14	12	13
Do	15	Urea	2	[2]3	[2]1
Do	15	Silicate	5	2	3
Alcohol soluble	15	....	84	99	91
Do	15	Phenolic	100	89	94

[1] Each value represents the average of eight specimens, which were individually exposed.

[2] These values represent gain in strength.

Table 5.--Effect of type and percentage of saturating resin on the loss in weight of phenolic-bonded core material after exposure to decay fungi

Type of saturating resin	Resin content	Loss in weight[1]		
		Fungus No. 617	Fungus No. 517	Average
	Percent	Percent	Percent	Percent
Water soluble	5	14.1	2.7	8.4
Water soluble + pentachlorophenol	5 + 2	1.6	1.5	1.5
Water soluble	10	.7	.3	.5
Do	15	.3	.0	.1
Alcohol soluble	15	[2].2	7.6	3.7

[1]Each value represents the average of five specimens, which were individually exposed.

[2]This value represents a gain in weight.

Table 6.--Description of sandwich constructions made with different core variables

Code number	Weight of base paper (3,000 sq. ft.)	Type of saturating resin	Saturating resin content	Type of bonding adhesives	Density
	Lb.		Percent		Lb. per cu. ft.
30W5P	30	Water soluble	5	Phenolic	1.64
30W15P	30	........do........	15	....do....	1.59
50W5P	50	........do........	5	....do....	2.17
[1]50W5FP	50	........do........	5	....do....	2.19
50W10P	50	........do........	10	....do....	2.35
50W15P	50	........do........	15	....do....	2.58
65W5P	65	........do........	5	....do....	2.55
30W5S	30	........do........	5	Silicate	2.12
30W15S	30	........do........	15	....do....	2.16
50W5S	50	........do........	5	....do....	2.40
50W10S	50	........do........	10	....do....	2.67
50W15S	50	........do........	15	....do....	2.97
65W5S	65	........do........	5	....do....	2.99
30W15U	50	........do........	15	Urea	2.54
50W15N	50	........do........	15	....	....
[2]$\frac{50}{30}W\frac{15}{5}P$	50 and 30	........do........	15 and 5	Phenolic	2.06
50A15P	50	Alcohol soluble	15	....do....	2.27

[1] Approximately 2 percent of pentachlorophenol was added to the saturating resin.

[2] The 50-pound paper contained 15 percent of resin, and the 30-pound paper contained 5 percent of resin. The 50-pound paper was assembled with flutes normal to the facings.

Table 7.--Effect of resin content of paper on strength of sandwich panels

Code number	Resin content	Shear stress developed in the bending test				Compressive strength	
		Corrugated web parallel to span		Corrugated web perpendicular to span		Dry	Wet
		Dry	Wet	Dry	Wet		
	Percent	Lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.
50W5P	5	52	11	....	....	35	8
50W10P	10	60	16	....	....	47	13
50W15P	15	74	33	22	12	63	17
50W5S	5	49	14	15	5	40	9
50W10S	10	67	17	22	6	53	11
50W15S	15	78	25	20	6	50	14
30W5P	5	28	13	....	....	30	9
30W15P	15	35	14	....	....	33	12
30W5S	5	26	7	13	5	25	7
30W15S	15	38	11	16	5	42	9

Table 8.--Effect of weight of paper on strength of sandwich panels

Code number	Nominal paper weight (3,000 sq. ft.)	Shear stress developed in the bending test				Compressive strength	
		Corrugated web parallel to span		Corrugated web perpendicular to span		Dry	Wet
		Dry	Wet	Dry	Wet		
	Lb.	Lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.
30W5P	30	28	13	....	....	30	9
50W5P	50	52	11	....	....	35	8
65W5P	65	55	13	....	....	50	9
30W5S	30	26	7	13	5	25	7
50W5S	50	49	14	15	5	40	9
65W5S	65	63	13	20	7	54	13
30W15P	30	35	14	....	....	33	12
50W15P	50	74	33	22	12	63	17
30W15S	30	38	11	16	5	42	9
50W15S	50	78	25	20	6	50	14

Table 9.--Effect of bonding adhesive on strength of sandwich panels

Code number	Adhesive	Shear stress developed in the bending tests				Compressive strength	
		Corrugated web parallel to span		Corrugated web perpendicular to span		Dry	Wet
		Dry	Wet	Dry	Wet		
		P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.
50W15P	Phenolic	74	33	22	12	63	17
50W15S	Silicate	78	25	20	6	50	14
50W15U	Urea	70	24	......	......	54	15
50W15N	....	63	28	12	6	42	9

Table 10.--Effect of certain variables as related to strength of sandwich panels

Code number	Variable	Shear stress developed in the bending test with corrugated web parallel to span		Compressive strength	
		Dry	Wet	Dry	Wet
		P.s.i.	P.s.i.	P.s.i.	P.s.i.
	EFFECT OF ALCOHOL-SOLUBLE RESIN SATURANT				
50A15P	Alcohol soluble	84	18	65	14
50W15P	Water soluble	74	33	63	17
	EFFECT OF FUNGICIDE				
50W5P	No fungicide	52	11	35	8
50W5FP	Pentachlorophenol	51	16	39	12
	EFFECT OF 30-POUND PAPER CROSS PLY				
50W15P	50 pound, 15 percent cross ply	74	33	63	17
$\frac{50}{30}W\frac{15}{5}P$	30 pound, 5 percent cross ply	62	30	53	13

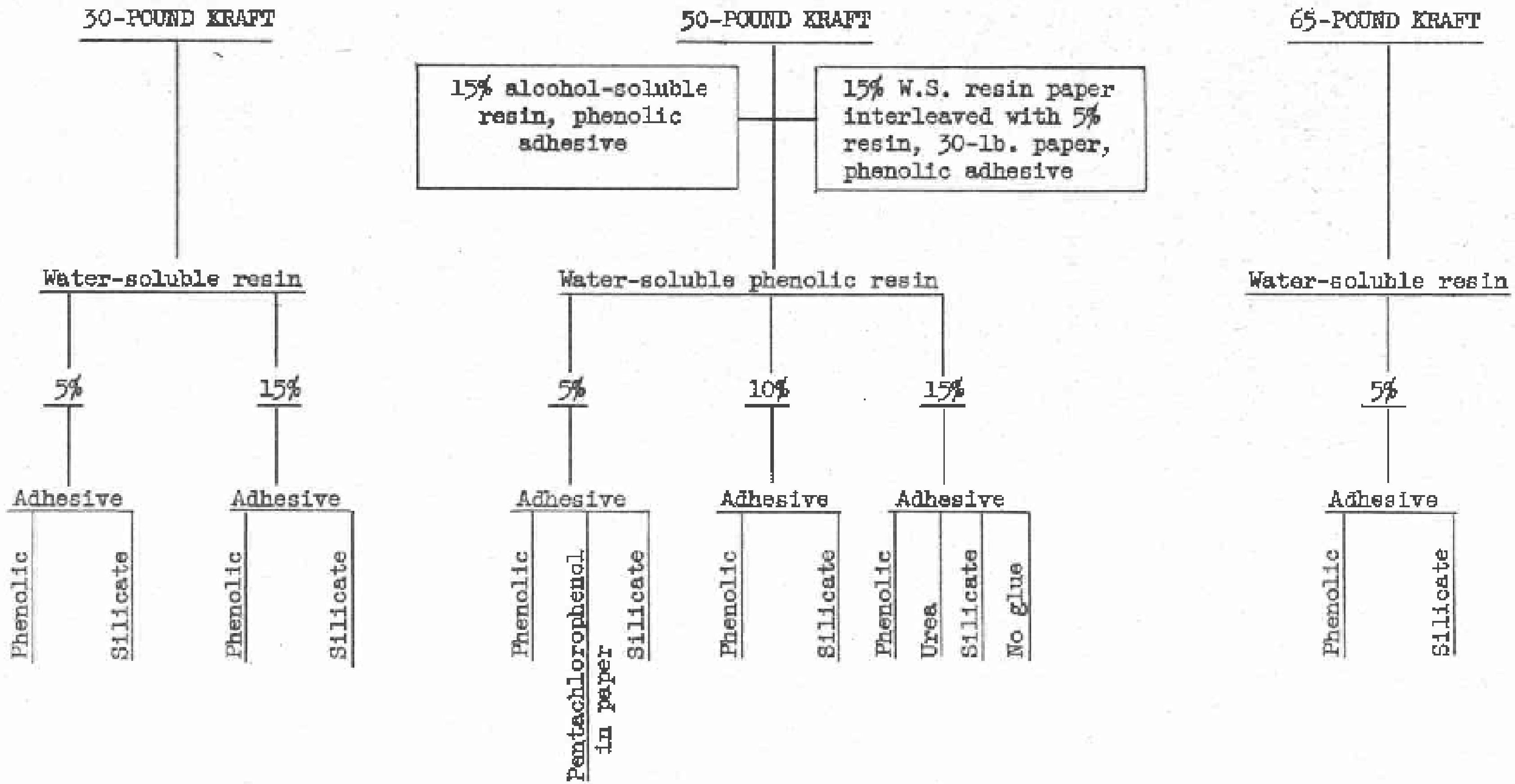


Figure 1. --Schematic diagram of various combinations of fiber, resin, and adhesives evaluated for paper honeycomb cores.

M 87480 F

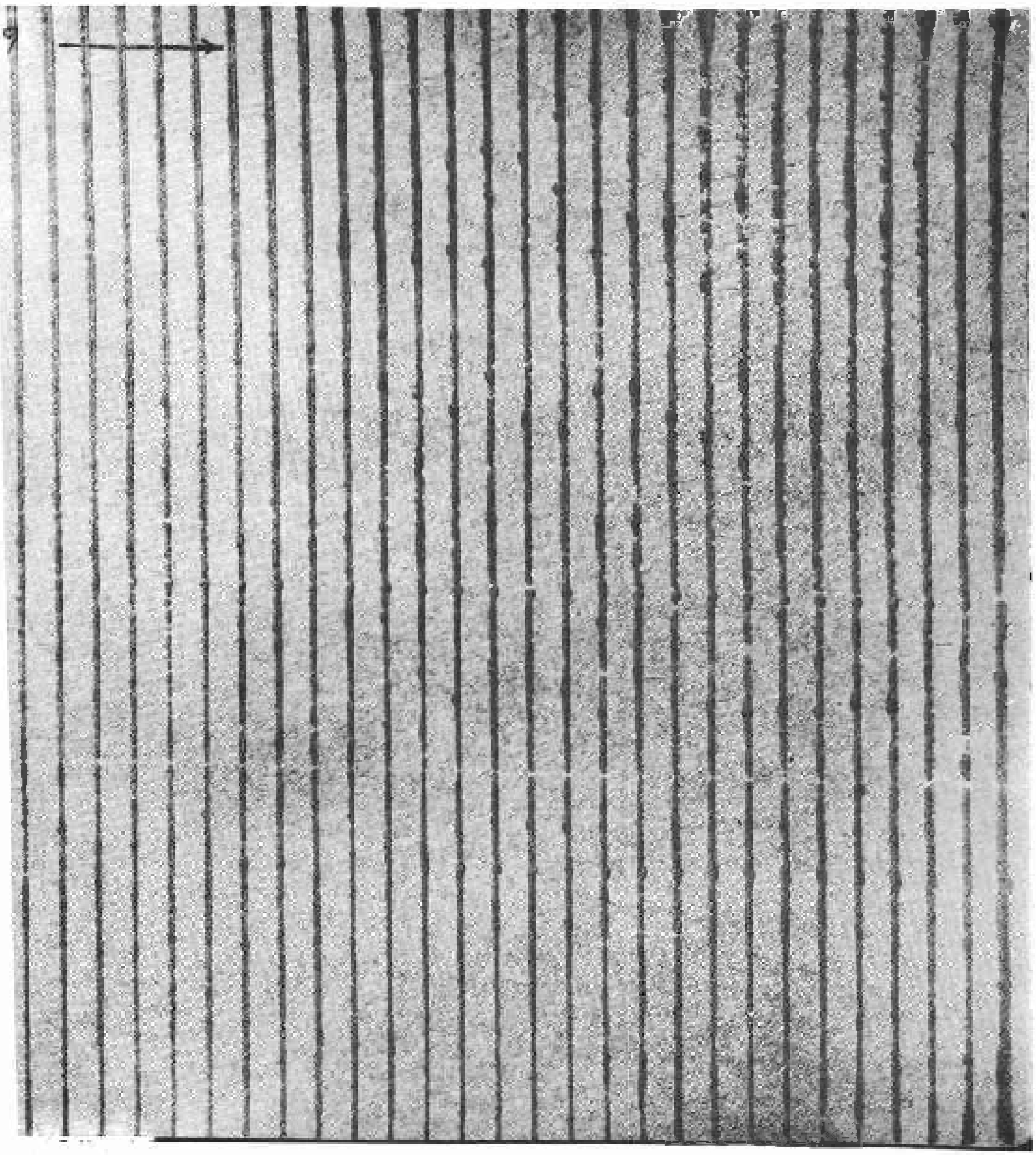


Figure 2. --Paper treated with water-soluble phenolic resin, showing glue stripes of phenolic resin. Machine direction of paper perpendicular to glue stripes.

ZM 77583 F

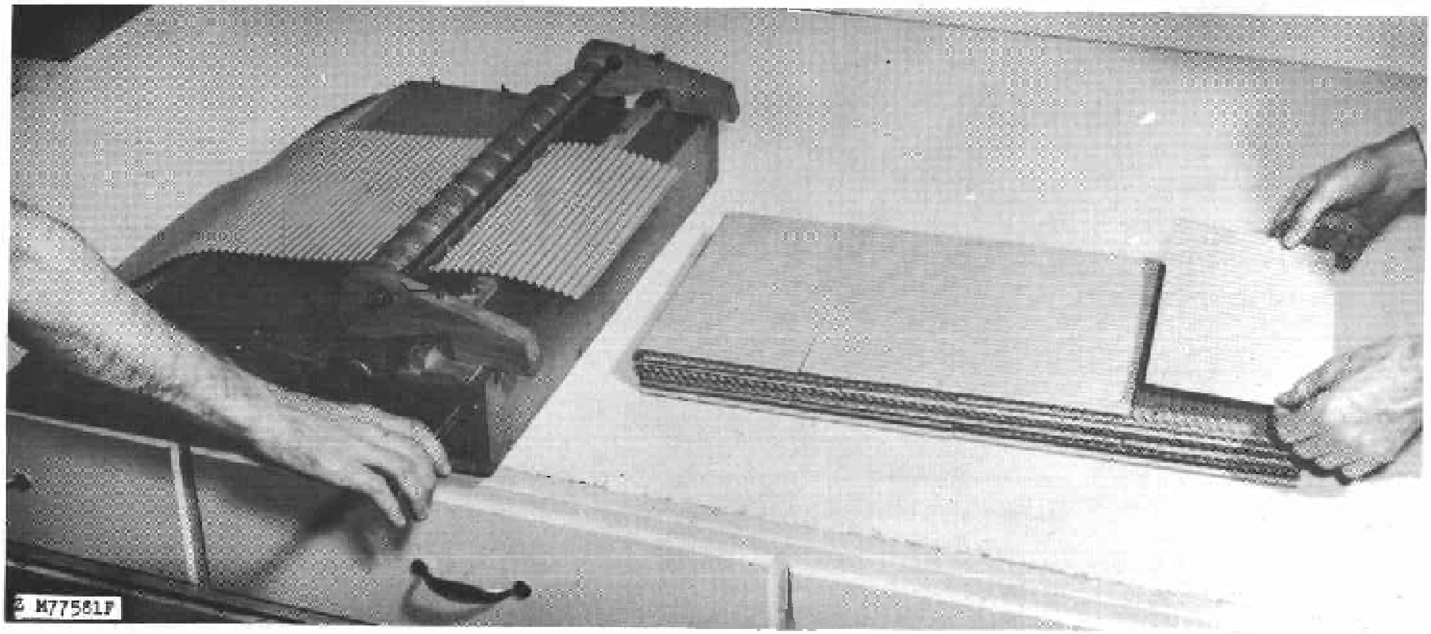


Figure 3. --Left, hand-driven glue spreader used to apply adhesives to the corrugated sheet. Right, fabrication of the core material.

ZM 77581 F

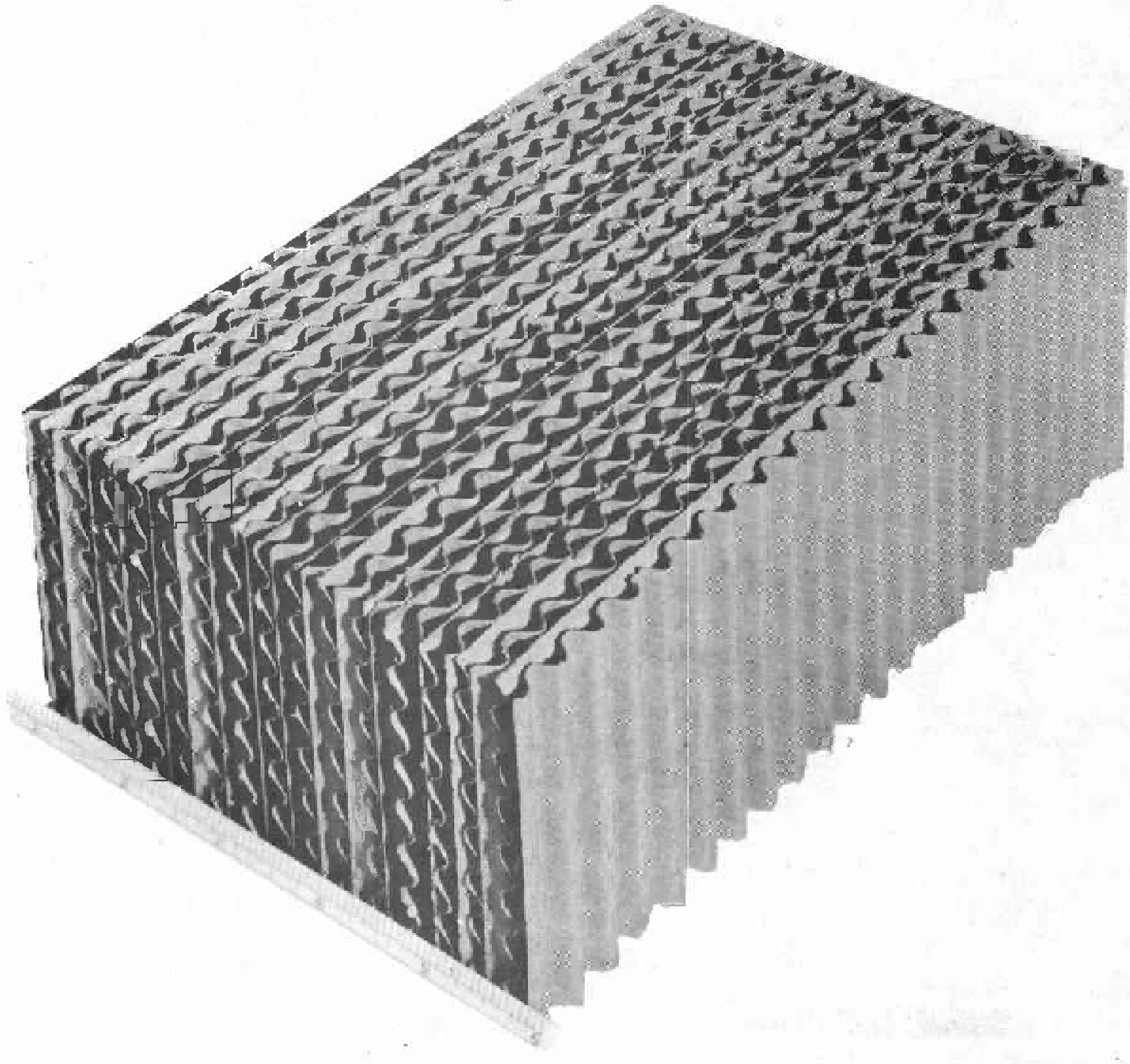


Figure 4. --Section of the XN type of core construction, that is, with flutes of alternate sheets at right angles.

ZM 87222 F

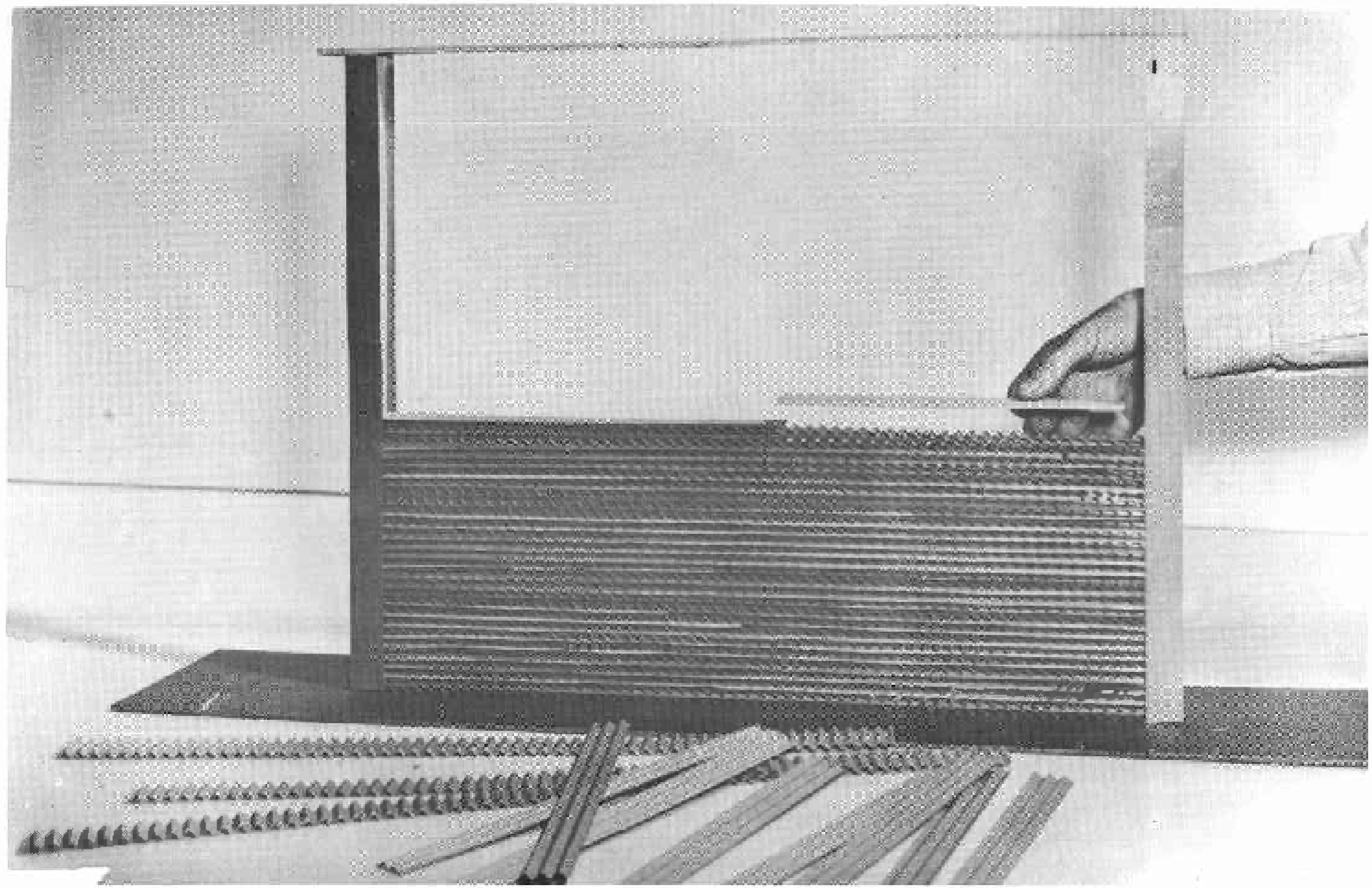


Figure 5. --Jig used to assemble strips of core material for sandwich panel in which no crest-to-crest bonding adhesive was used.

ZM 77582 F

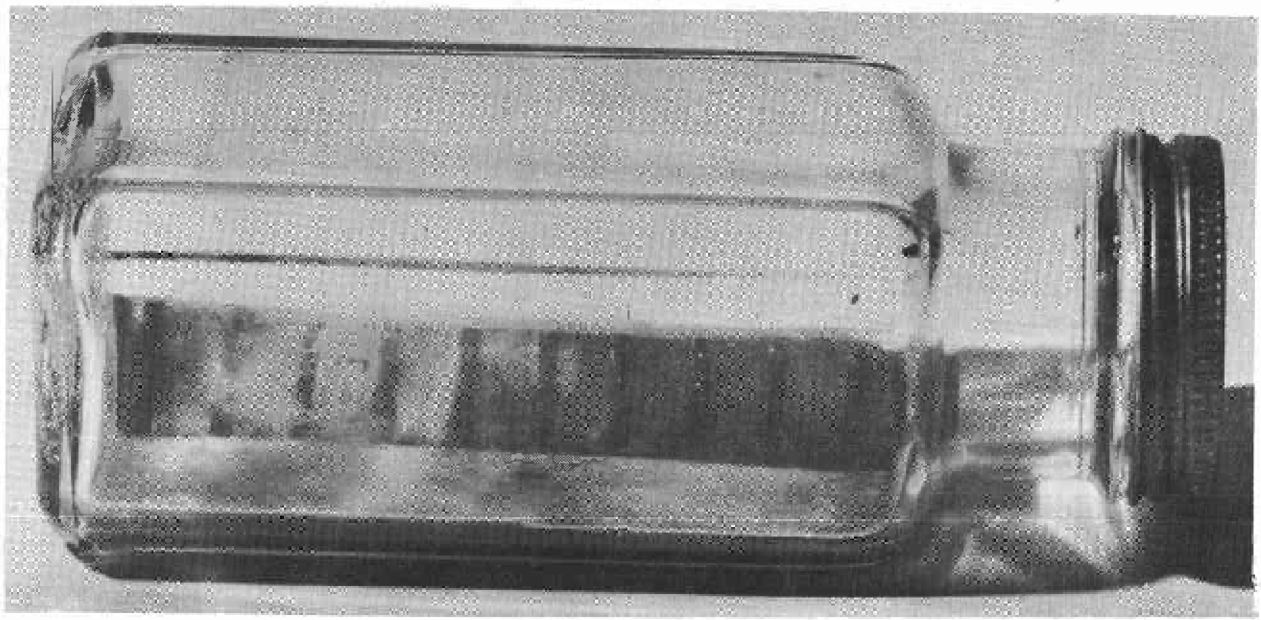


Figure 6. --Bottle decay test showing placement of glue-striped specimen on fungus mat.

ZM 77546 F

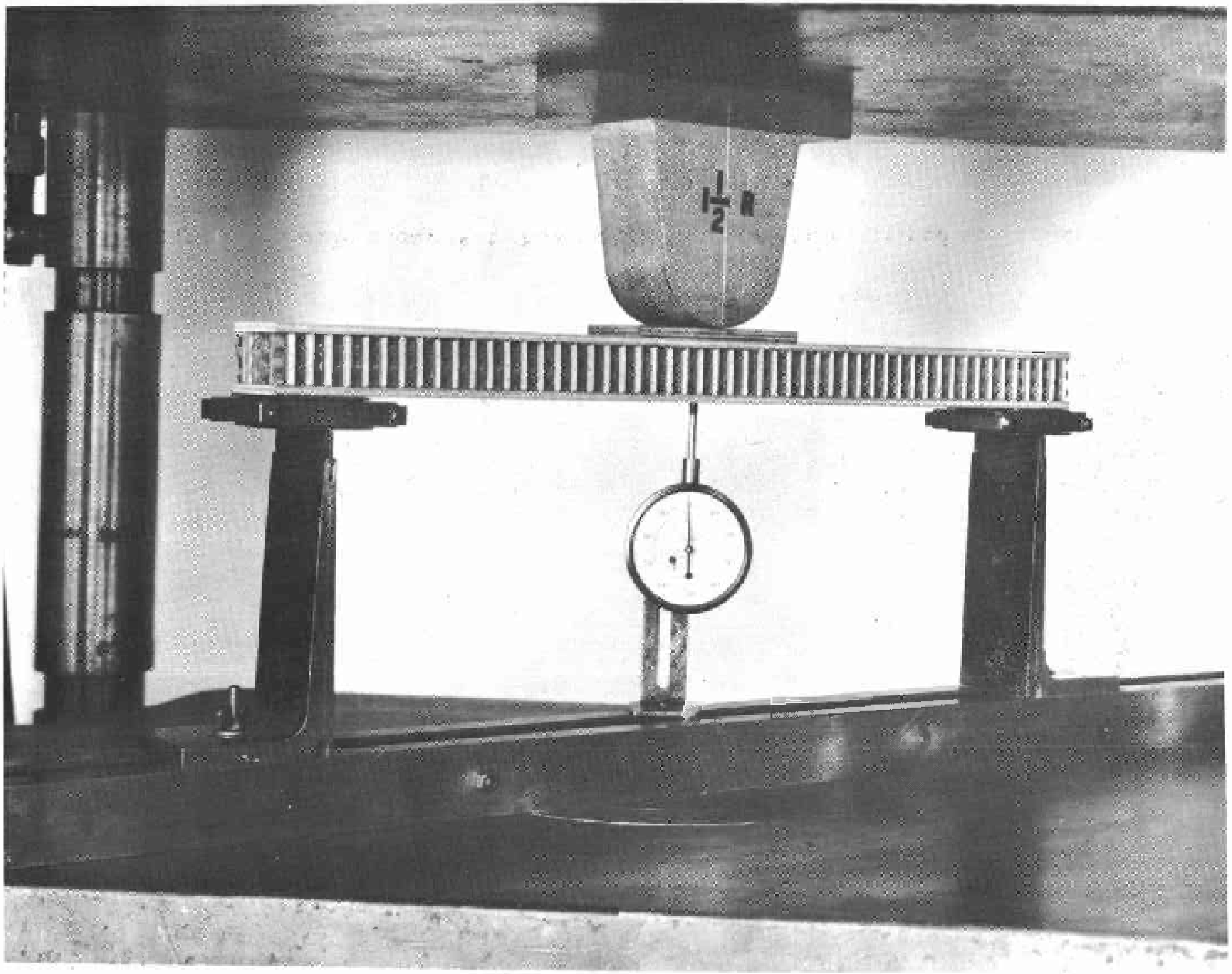


Figure 7. --Arrangement of apparatus used to test sandwich specimens in bending.

ZM 77580 F

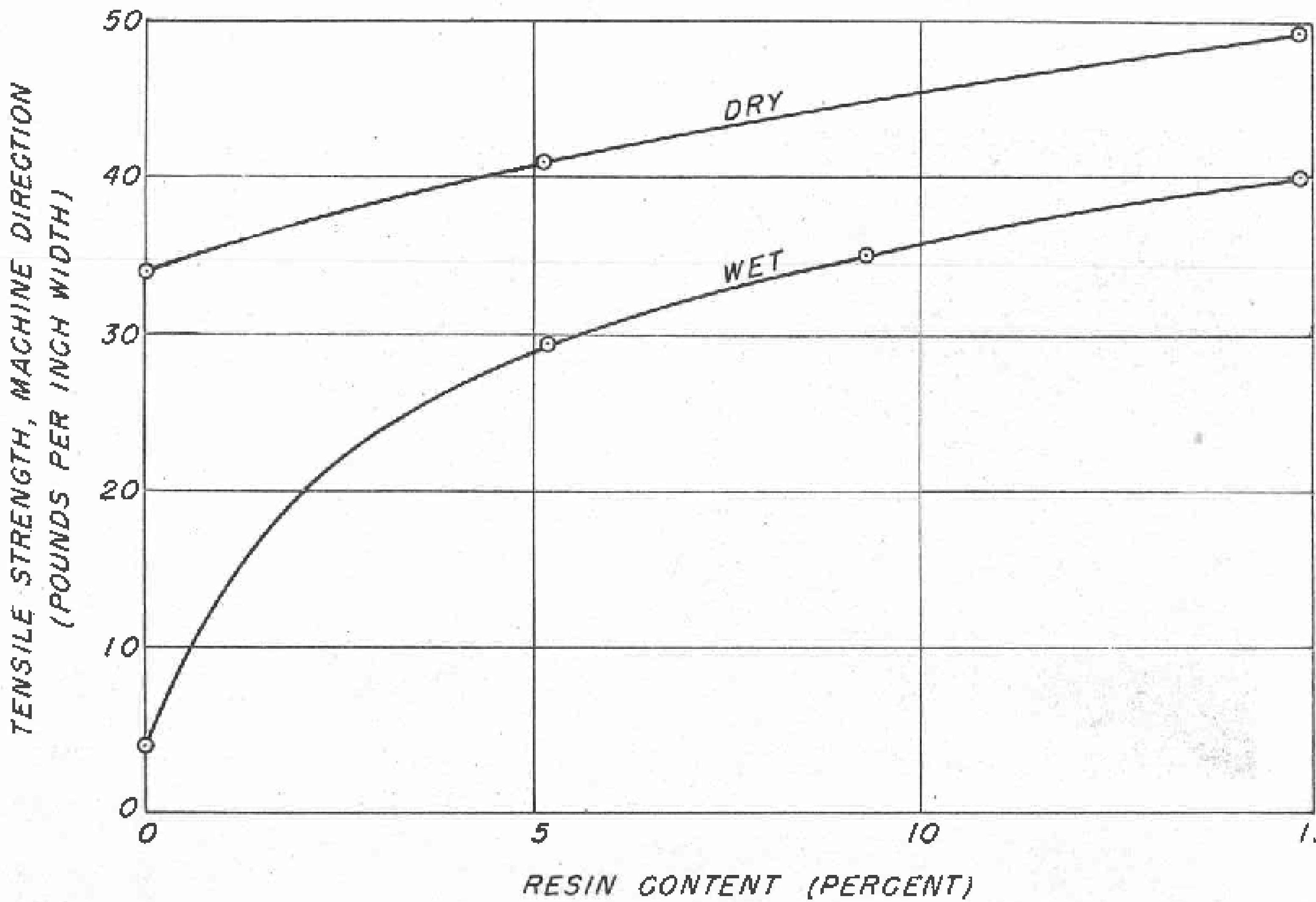


Figure 8. --Effect of resin content on the tensile strength of 50-pound paper tested under dry and wet conditions.

M 87481 F

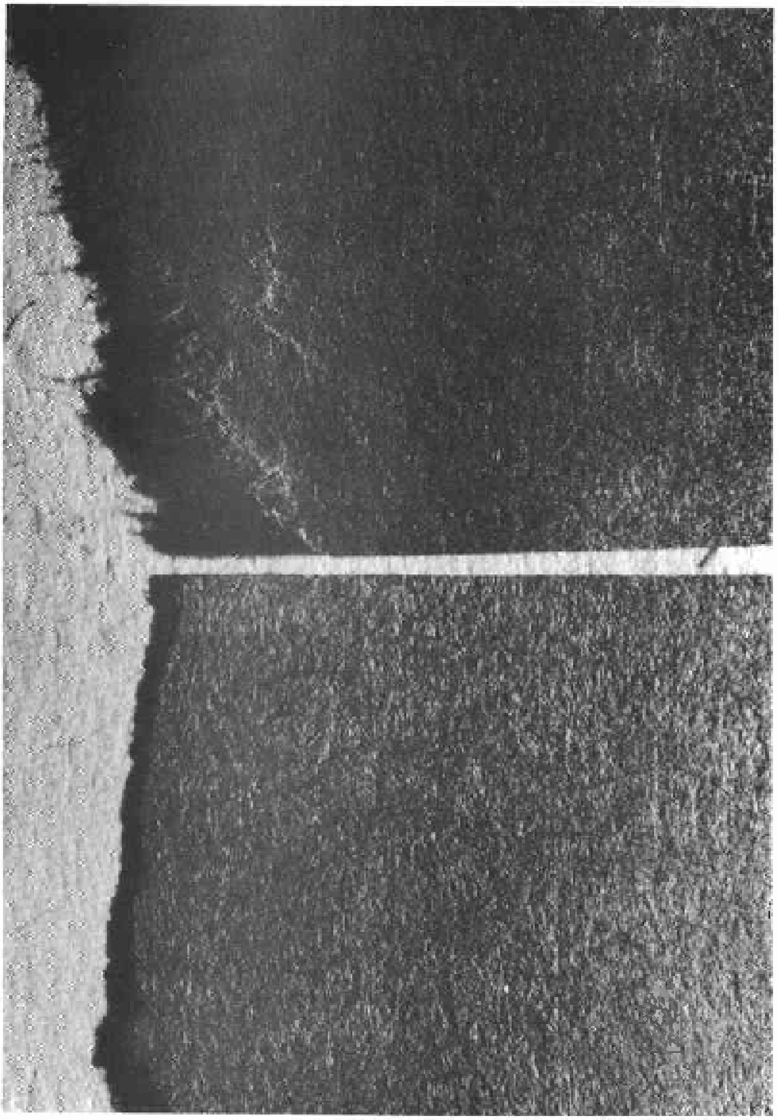


Figure 9. --Type of tensile failure for samples of resin-treated paper tested wet after soaking 48 hours in water. Top, alcohol-soluble phenolic resin paper; bottom, water-soluble phenolic resin paper. Magnification 7 times.

ZM 77584 F

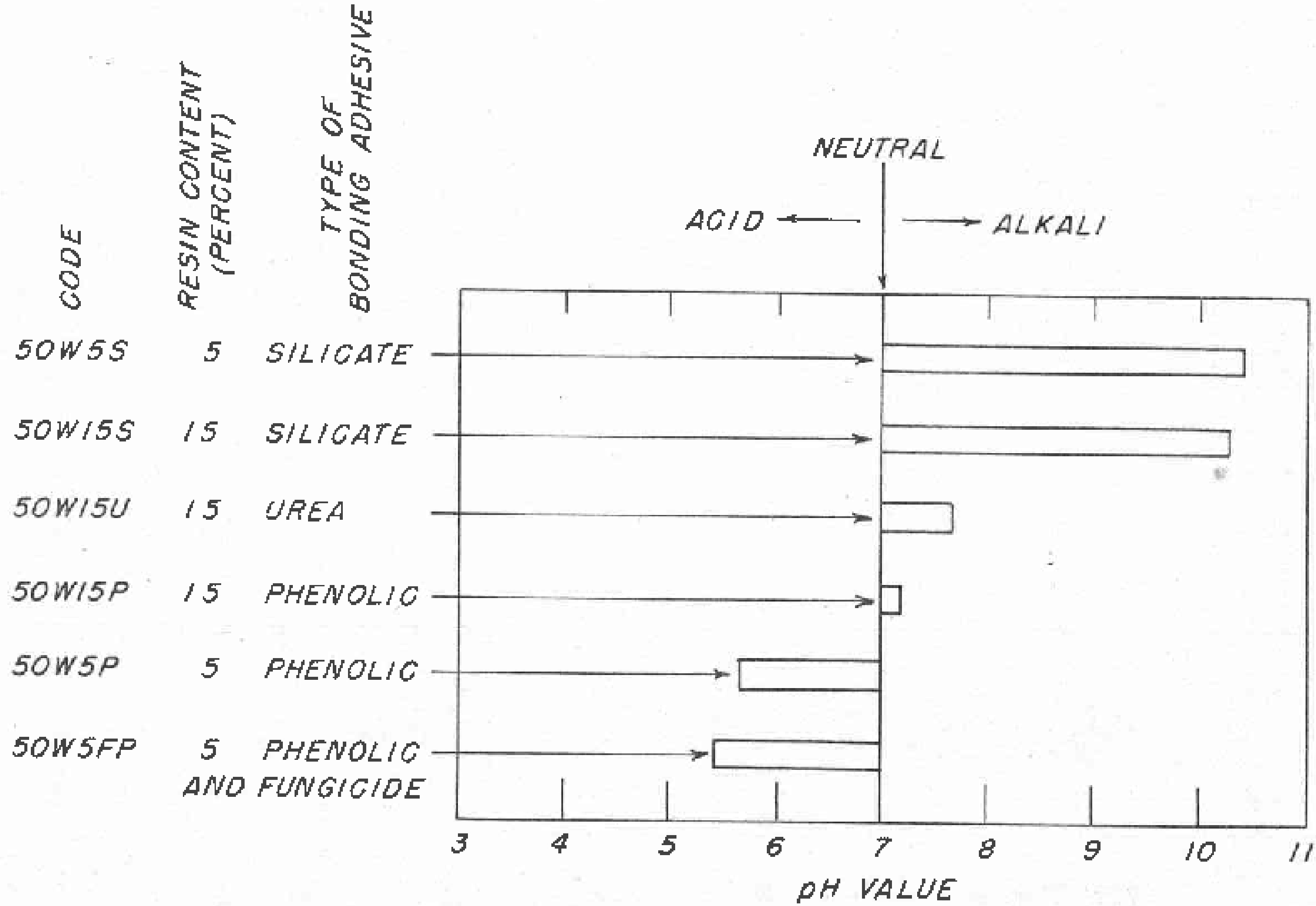


Figure 10. --pH values of honeycomb core material made from 50-pound neutral kraft paper.

M 87483 F

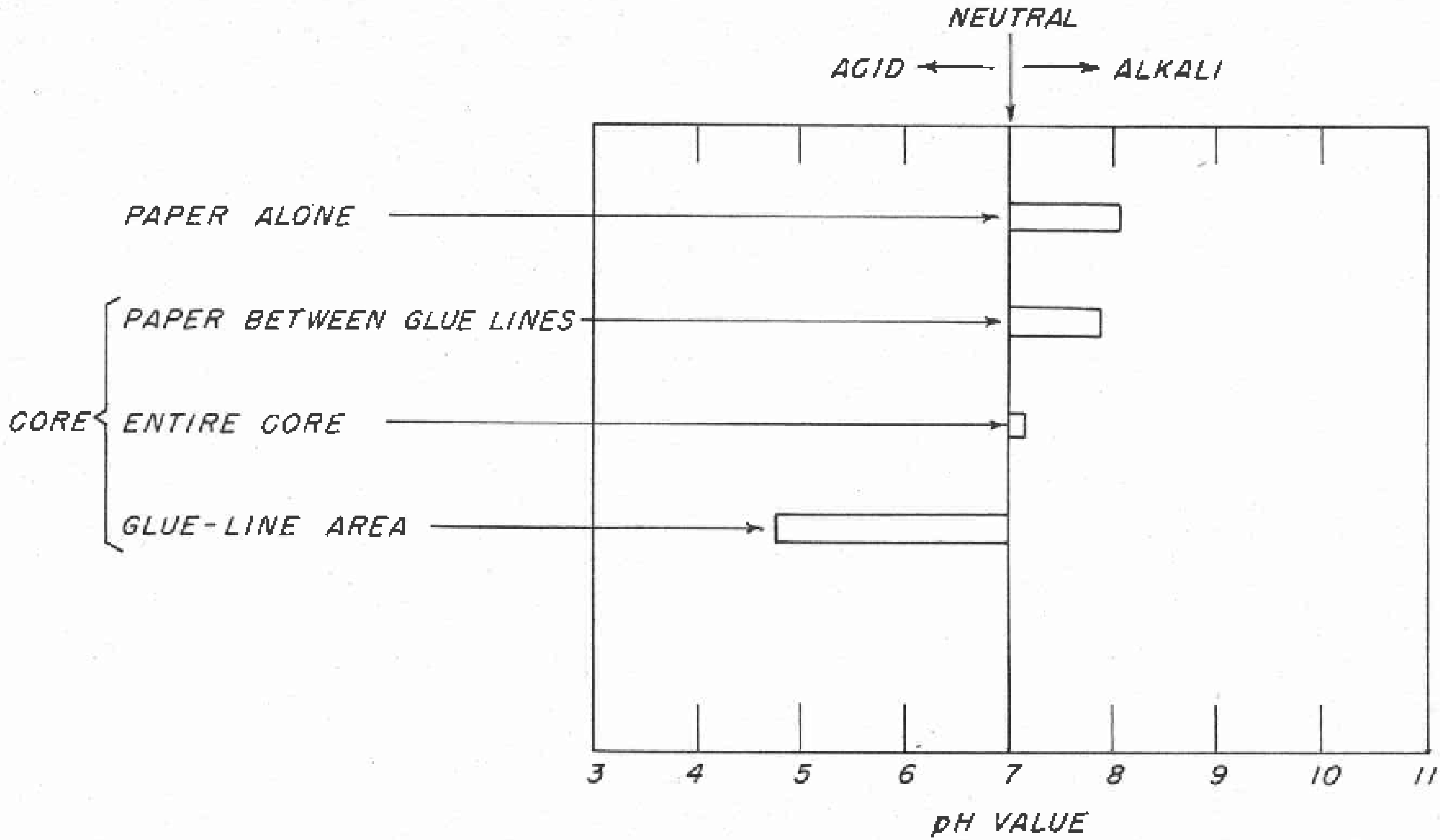


Figure 11.--pH value of honeycomb core material made from 50-pound kraft paper containing 15 percent of resin and bonded with phenolic adhesive.

M 87482 F

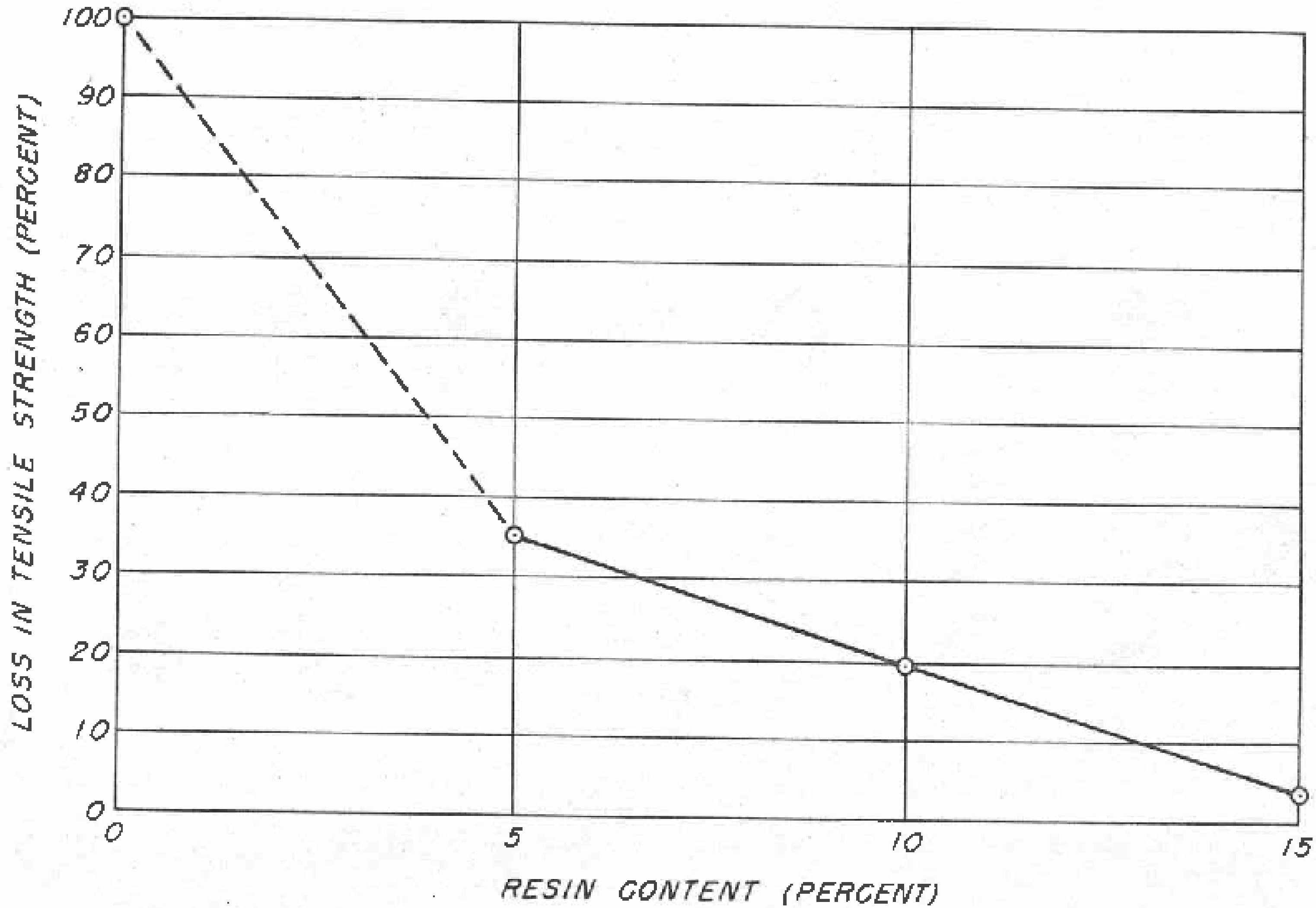


Figure 12.--Effect of resin content of 50-pound kraft paper on the average loss in tensile strength after 2 months' exposure to decay fungi.

M 87487 F

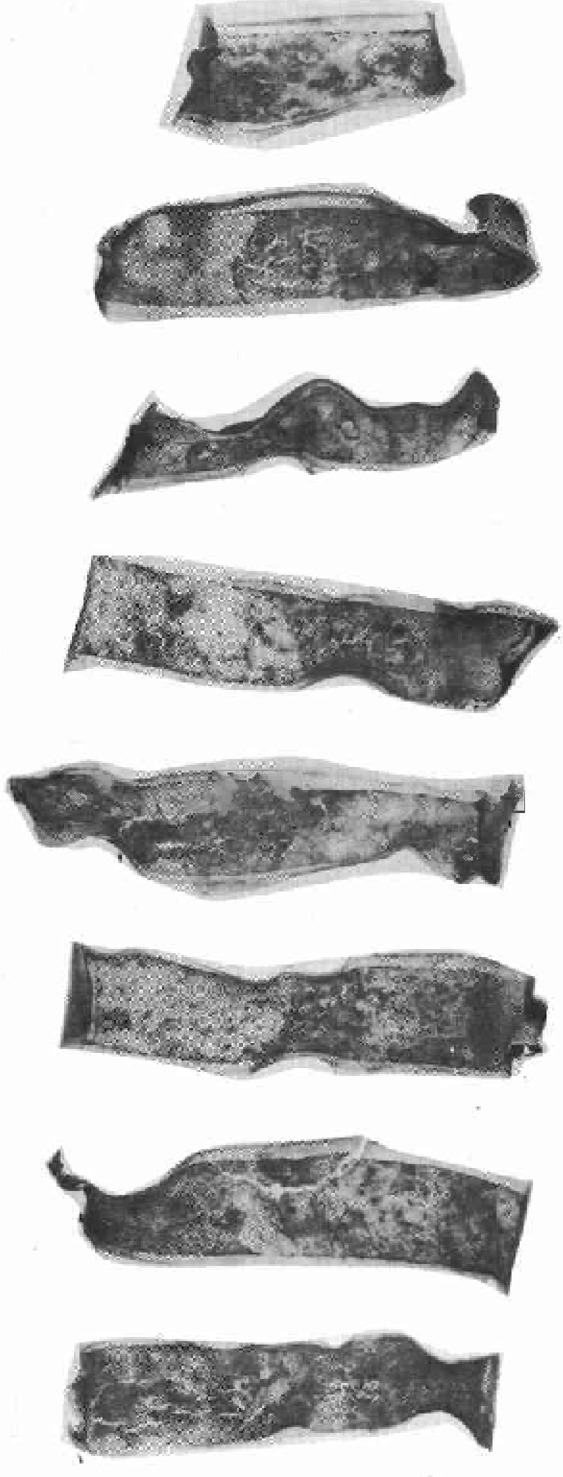


Figure 13.--Specimens of unimpregnated kraft paper after 2 months' exposure to fungus No. 617. Loss in tensile strength for these specimens was 100 percent.

ZM 77624 F

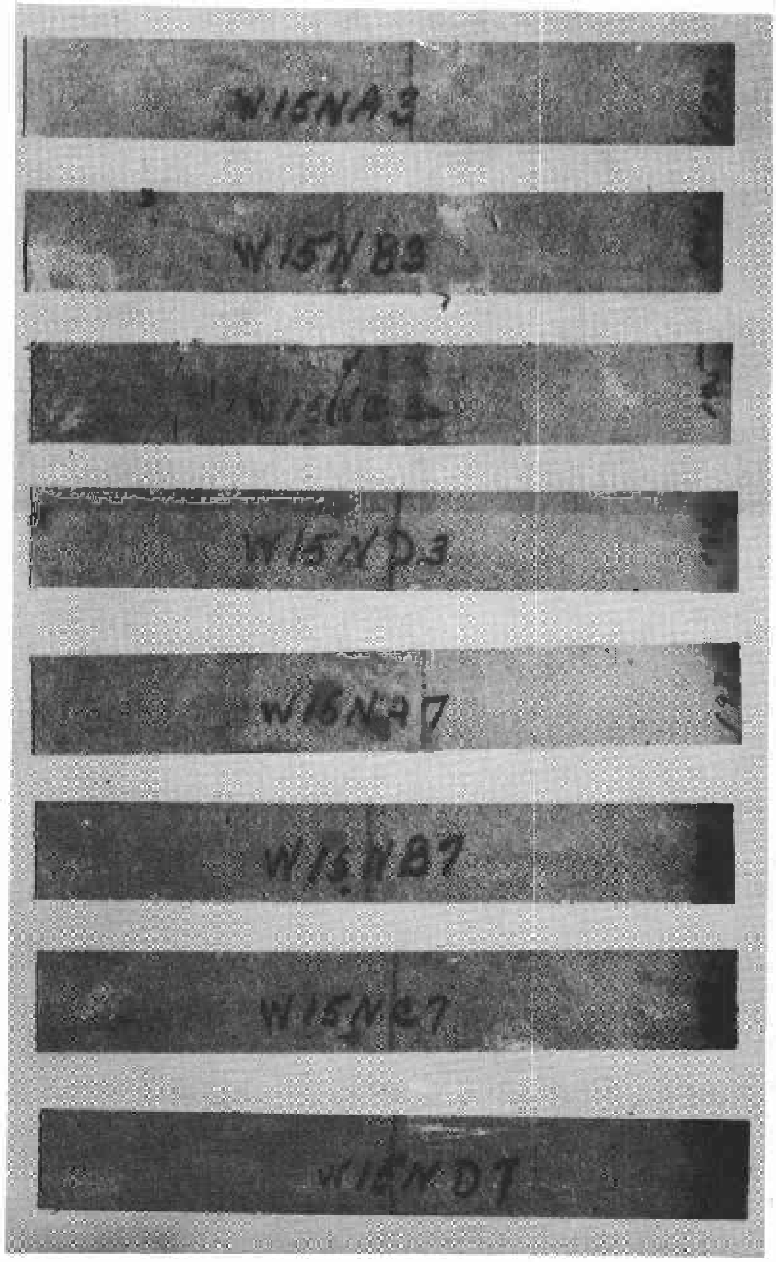


Figure 14. --Specimens of kraft paper impregnated with 15 percent of water-soluble phenolic resin after 2 months' exposure to fungus No. 617. Average loss in tensile strength for these specimens was 6 percent.

ZM 77616 F

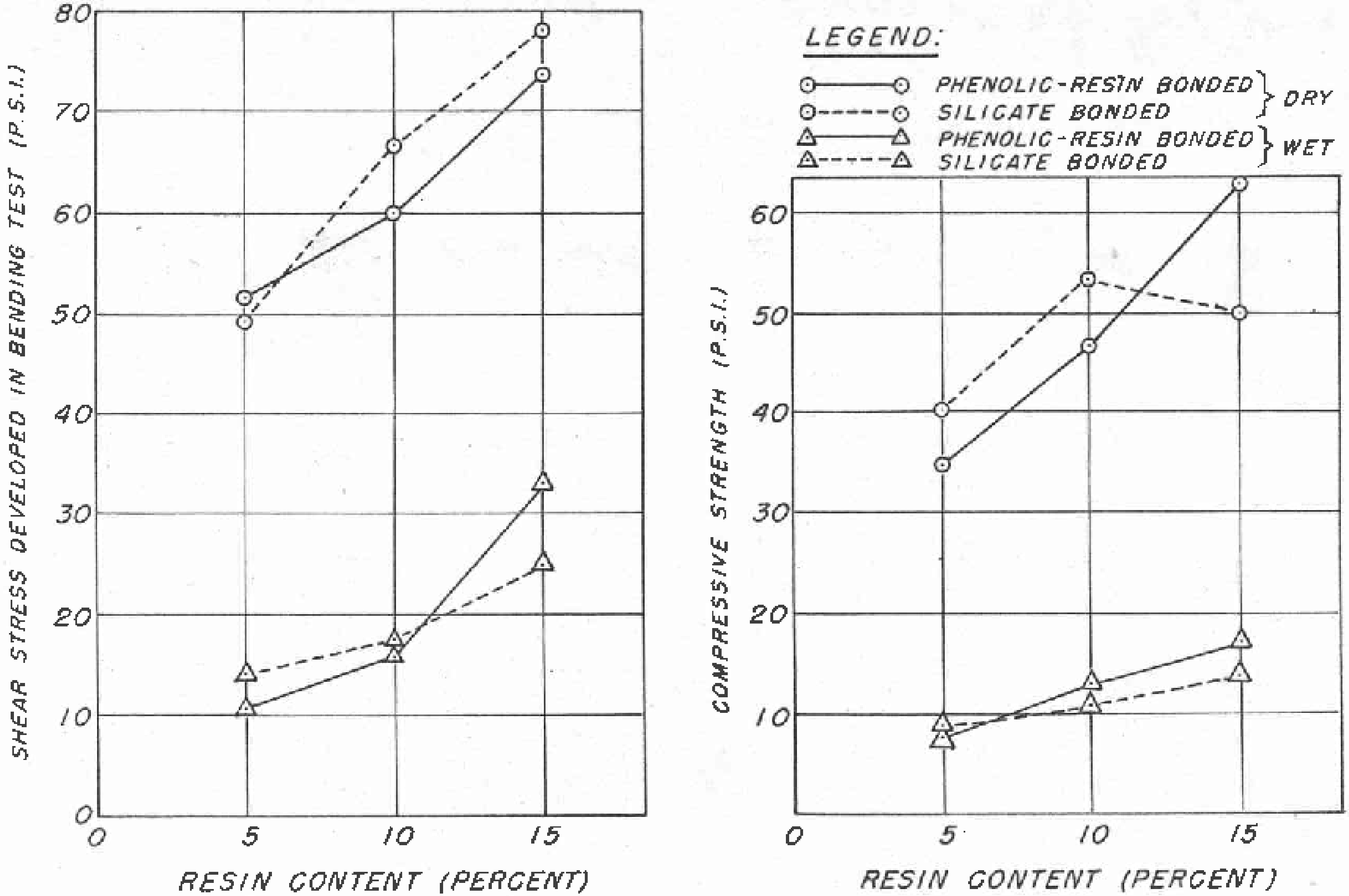
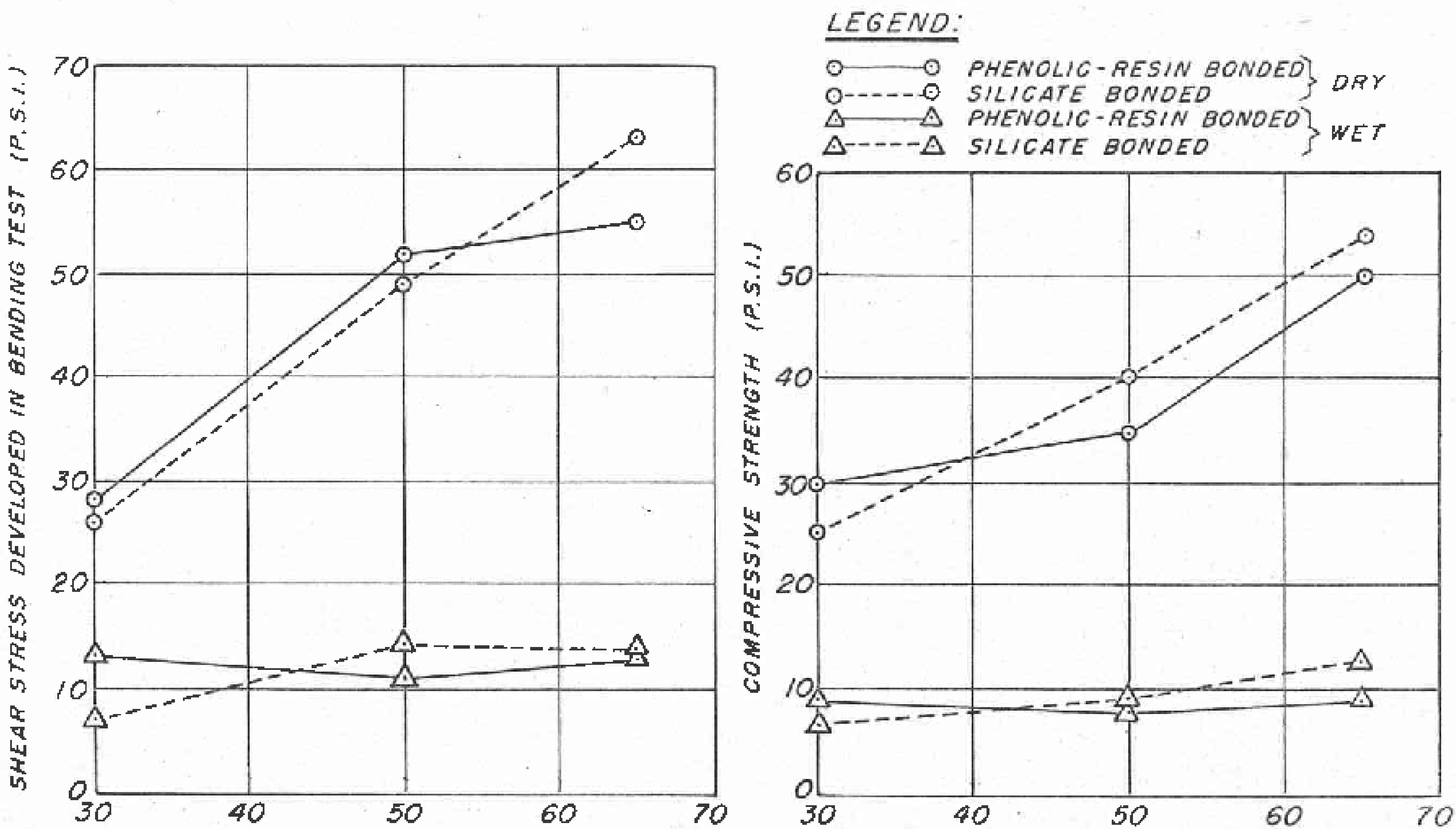


Figure 15. --Effect of resin content on strength of sandwich panels having core material made from 50-pound paper and bonded with phenolic and silicate adhesive.

M 87486 F



PAPER WEIGHT (POUNDS PER 3,000 SQUARE FEET)

Figure 16. --Effect of paper weight on strength of sandwich panels made from 5 percent resin paper and bonded with phenolic and silicate adhesive.

M 87485 F

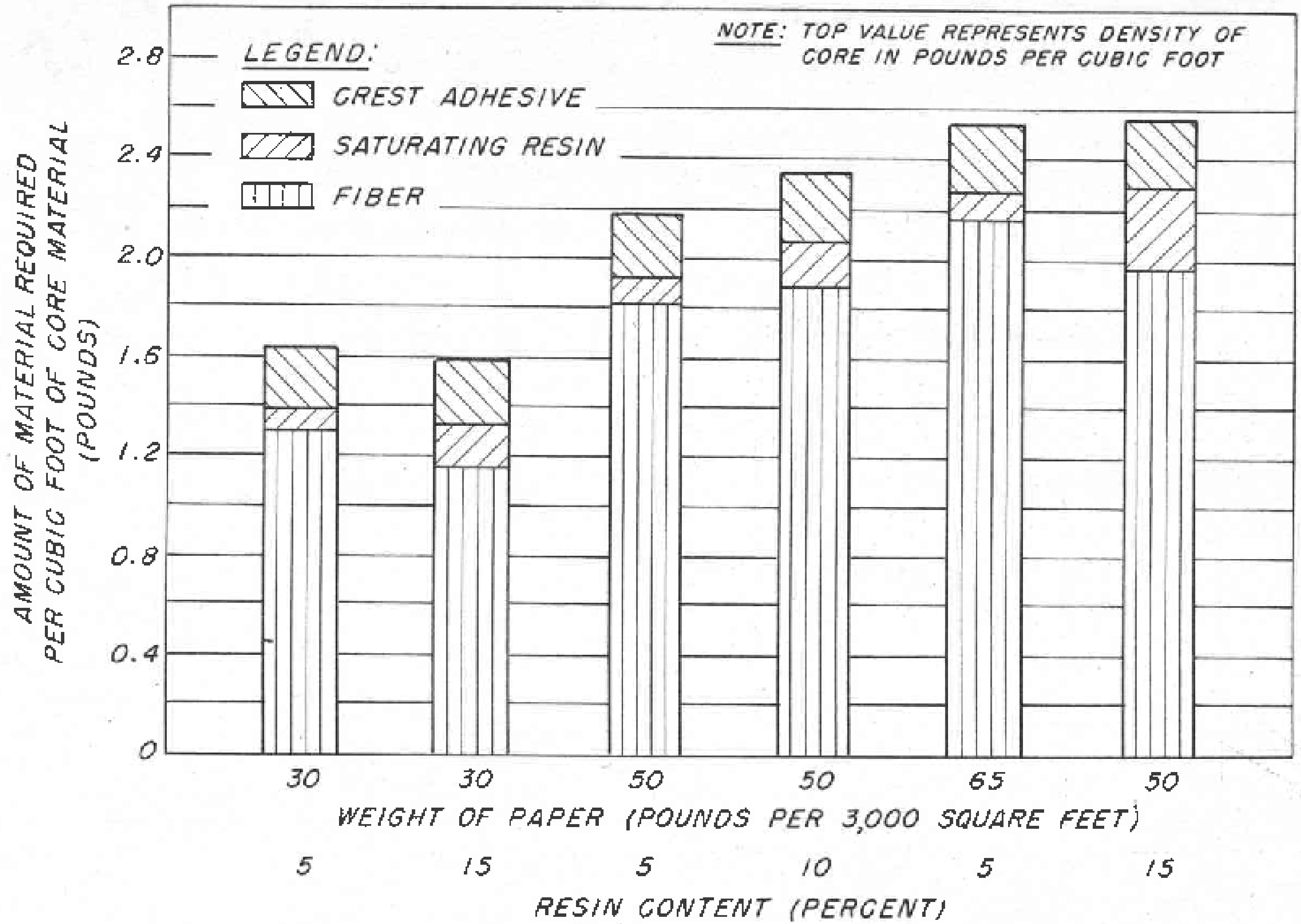


Figure 17.--Proportions of fiber, resin, and adhesive used in phenolic-bonded cores.

M 87484 F

Seidl, Robert Joseph
Paper honeycomb cores for structural building panels: Effect of resins, adhesives, fungicide, and weight of paper on strength and resistance to decay, by R. J. Seidl and others. 3rd. ed. Madison, Wis., U. S. Forest Products Laboratory, 1961.
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