PRELIMINARY REPORT ON THE STRENGTH OF FLAT SANDWICH PLATES IN EDGEWISE COMPRESSION

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PRELIMINARY REPORT ON THE STRENGTH OF FLAT SANDWICH PLATES IN EDGEWISE COMPRESSION[1]

By

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Summary

This report presents data on the edgewise compressive strength of short columns of flat sandwich plates. It contains the results of a limited number of tests that were made on sandwich constructions to determine the failing stress of the facing material. This report also presents some mechanical properties of the core and facing materials used in the sandwich plates, and describes the methods employed to obtain then.

Introduction

In the design of sandwich constructions the maximum stress of the facings that is obtained in an edgewise compression test of the construction is an important criterion in the determination of the suitability of the component materials. The data on the strength and related properties of sandwich plates are presented in this report to provide assistance in the development of theories and formulas for this criterion.

These data are the results of tests for maximum strength on 169 sandwich constructions. The results were obtained by testing six facing materials in 29 combinations with 10 core materials. In sone of the 29 combinations the thicknesses of the component materials were varied, resulting in the 169 sandwich constructions.

Data are presented to show a few properties of the facing and core materials that are related to the edgewise compressive strength of the sandwich. The methods that were employed for obtaining these properties are discussed.

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[1] This report is one of a series of progress reports prepared by the Forest Products Laboratory. Results here reported are preliminary and may be revised as additional data become available.

Materials

Facing Materials

The facing materials that were used and tested in the sandwich constructions are (1) rolled metallic sheets, (2) plastic laminates, and (3) veneer laminates. They are described as follows:

Rolled metallic sheets.--24SH aluminum sheets, 0.005 inch in thickness, and 24 ST alclad aluminum sheets in 0.008, 0.012, 0.018, 0.020, and 0.032 inch thicknesses were employed. The aluminum sheets in each sandwich construction were placed on the two sides of the core with the lengthwise or rolled direction parallel to the direction of the compressive stress applied in the tests.

Plastic laminates.--Cross-laminated glass cloth facings were used in 2-, 4-, 8-, and 16-ply constructions in conjunction with end-grain balsa cores. These facings were impregnated to a resin content of about 55 percent (based on total weight) with a suitable resin. When glass cloth was used with other core materials, 3-, 6-, 10-, and 16-ply constructions were made with about 45 percent resin content. (Note: The higher resin content of the glass cloth laminate employed with the balsa was found necessary for the proper fabrication of the sandwich constructions. In later panels, not reported here, means were found by which the resin content was satisfactorily reduced to 45 percent.) The glass cloth sheet incorporated in these constructions was 0.003 inch thick, 38 inches wide, and weighed 2.09 ounces per square yard. It was of a plain type of weave.

Cross-laminated papreg was used in 0.009, 0.022, 0.027, 0.042, and 0.066 inch thicknesses. The base paper was made from an unbleached black spruce, Mitscherlich type, sulfite pulp. This paper, 2.5 mils thick, was impregnated with 36.5 percent of a thermosetting phenolic resin. The percentage is based on the weight of the treated paper.[2]

These plastic laminates were placed on the two sides of their respective core materials with the machine direction of the outside sheets parallel to the direction of the stress applied in the tests.

Veneer laminates. --Laminatedyellow-poplar veneer was used as a facing material on resin-impregnated pulpboard cores. The laminated facings were made of from 1 to 10 sheets of 0.01-inch rotary-cut veneer, bonded with sheets of resin-impregnated paper. The directions of the grain of the individual veneers were parallel to each other.

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[2] Additional information may be found in "Strength and Related Properties of Forest Products Laboratory Laminated Paper Plastic (Papreg) at Normal Temperature." Forest Products Laboratory Report 1319, revised.

Aircraft spruce plywood was mads of a three-ply construction having 1/48-inch faces and 1/32-inch core.

Both yellow-poplar and spruce facing materials were placed on thle two sides of their respective core materials with the grain direction of the outside plies parallel to the direction of the stress applied in the tests.

Core Materials

The core materials that were used and tested in the sandwich constructions may be placed in four classes, (1) wood and plywood, (2) expanded plastics, (3) pulpboard, and (4) honeycomb structures. They are described as follows :

Wood and plywood.--Balsa wood was used in combination with all of the types of facing material. The balsa that is referred to as "end grain" (E.G.) was placed between the two facings with the longitudinal or grain direction perpendicular to the facings. This was accomplished by first surfacing the rough planks, then cutting the planks across the grain to make blocks of the required thickness of the core in the sandwich. These blocks were glued edge to edge to form the core. In general, a single sandwich plate contained blocks from the same plank, but the orientation of their radial and tangential directions was not confined to one given direction in the plane of the panel.

The balsa that is referred to as "loaded flat, perpendicular to grain" was placid between the two facings with the grain direction parallel to the plans of the facings and perpendicular to the direction of the load applied in the tests, This construction was made by gluing, edge to edge, planks that had been smoothly surfaced to the required thickness of the core material.

The balsa that is referred to as "loaded parallel to grain" was placed between the two facings with the grain direction parallel to the plane of the facings and parallel to the direction of the load applied in the tests. For this construction the planks of the required thickness were glued edge to edge to provide sufficient width.

The spruce plywood that was used as a core material with aluminum facings was made in the following constructions: (1) the 3/16-inch thick plywood vas made of 1/32-inch faces and core and with 1/20-inch cross bands; (2) 3/8-inch thick plywood was made of seven plies of 1/16-inch veneer: (3) 7/8-inch thick plywood was made of seven plies of 1/8-inch veneer. The grain direction of the outer ply in each construction was placed parallel to the direction of the load applied in the tests.

Expanded plastics.--The expanded plastics consisted of solid materials that had been foamed, or expanded, to produce a large number of small voids in the mass thereby reducing the over-all specific gravity. Each of the core materials of this group had a fairly uniform cell structure and an over-all specific gravity of about 0.10. The individual cells varied in size from about 0.01 to 0.04 inch in diameter.

Core materials of calcium alginate, cellular cellulose acetate, cellular hard rubber, British hard rubber, and special sponge rubber were used. They were in the form of flat plates that ranged in thickness from 1/2 inch to 1-1/2 Inches, and in width from 2-5/8 inches to 24 inches and in length from 1 to 10 feet. The natural skin that covered the manufactured product was removed from all faces of these materials in their preparation for use as cores. The original direction of the thickness dimension was used as the thickness direction of the core in the sandwich. The other two directions, lengthwise and crosswise, were placed indiscriminately in the direction of the stress applied in the tests.

Pulpboards[3].--The impregnated pulpboards used consisted of irregularly arranged wood fibers that adhered to each other and were formed into sheets of low density, porous core material. The quality of the adhesion and strength of the pulpboards were increased by the addition of resin. The resin-impregnated pulpboards used had resin contents ranging from 0 to 70 percent. The percentage is based on the total weight of the impregnated board when dry. The specific gravities as well as the strengths of the core materials increase with increases in resin content. These boards were not stripped of their outer skin, prior to their use as cores, as were the expanded plastics. This skin prevented excessive penetration into the core material of the glue to affix the facings. The boards were manufactured in thicknesses of 3/8 and 3/4 inch and were used unaltered.

Honeycomb structures.--The honeycomb material that was used in this study was made of either resin-impregnated glass cloth or paper sheets. The glass cloth sheets were the same as those used in making the facings. The paper sheets were made of 4-mil kraft paper, corrugated, and pretreated with 10 percent of phenolic resin. Both kinds of sheeting were impregnated with a contact type of resin and assembled in large separate blocks. The crest of one corrugated sheet was placed on the crest of another forming tubes about 0.18 inch in diameter. The cores for the sandwich were sliced from the blocks so that the thickness dimension of the sandwich was parallel to the axes of the tubes. This core material was oriented in the sandwich so that planes of the corrugated sheets were perpendicular to the direction of 1oading.

Fabrication of Sandwich Plates

Facing and core materials were combined to form 169 different sandwich constructions. Each construction consisted of sheets of facing material glued to a core to form flat sandwich plates, In some cases more than one layer of core material was required to form the core so that several layers were glued together. The thicknesses of the core and facing materials in these plates are listed in tables 1 through 5.

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[3] Addititional information may be found in "Resin Treated Pulpboard Core Material for Sandwich Construction." Forest Products Laboratory Report R1623.

Three sizes of sandwich plates were made: (1) square, 12 inches on a side, (2) rectangular, 12 inches long and 4 times the thickness plus 1 inch in width, (3) rectangular, 2 inches wide and 4 times the thickness plus 1 inch in length. In the fabrication of the rectangular plates, 12 inches long, strips of wood were placed between the facings in conjunction with the core material. These strips, 1/2 inch wide, 12 inches long, and the same thickness as the core material, were located at both 12-inch edges as shown in figure 1.

Methods of Test

Tests of Sandwich Constructions

Compression and tension tests of sandwich constructions were made, except for a few modifications, according to the tentative methods described in Forest Products Laboratory Report 1556.[4]

Compression edgewise.--The compression tests in the edgewise direction were made according to the procedure given in section 6 of report 1556.[4] Although this method was used and found satisfactory for a majority of the specimens, sone of them failed adjacent to one of the loaded edges. These failures were subsequently prevented in two different ways, (1) by the addition of wooden strips, shown in figure 1, to provide internal support of the facings at the loaded edges in conjunction with the steel clamps described in report 1556,[4] and (2) by the adoption of plaster disks, as shown in figure 2, The specimens equipped with the plaster disks were prepared by grinding the bearing edges of the facings smooth ana parallel and removing 1/4 inch of the core material at each bearing end. The protruding edges of the faxing material were cast in plaster disks so that the bearing surfaces of the facings were flush with the surfaces of the disks.

The particular specimens that were modified in each of these ways are indicated by footnotes in tables 1 through 5.

Tension flatwise.--The tension tests in the flatwise direction were made according to the procedure given in section 8 of report 1556.[4] The sandwich material for the specimens used in these tests was obtained from the 12-inch square plates as shown by the cutting diagram (fig. 3).

Compression flatwise.--The compression tests in the flatwise direction were made according to the procedure given in section 7 of report 1556.[4] The sandwich specimens used for these tests were also obtained from the 12-inch square plates.

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[4]Tentative Methods for Conducting Mechanical Tests of Sandwich Constructions. Forest Products Laboratory Report 1556.

Tests of Core Material

Compression and shear tests of the core materials were made according to the tentative methods described in Forest Products Laboratory report 1555[5] with an additional method for determining the modulus of rigidity.

Compression flatwise.--Compression tests of the special sponge rubber were made in the flatwise direction according to the procedure described by paragraphs 5 through 10 and figure 2 of report 1555.[5]

Compression tests of honeycomb materials were made on specimens 2 inches square by 6 inches long (length parallel to axes of cells). These specimens were tested between the heads of a testing machine by applying the load in a direction parallel to the axes of the cells. A 2-inch Marten's mirror arrangement was used for measuring the deformations.

Other core materials were tested in compression flatwise as sandwich constructions as previously described.

Conpression edgewise. --Compression tests in the edgewise direction were made according to the procedure described in paragraphs 12 througn 17 of Forest Products Laboratory report 1555.[5] Materials for these tests were matched with those used as cores of the sandwich constructions tested in edgewise compression. Core materials from the square plates, which were 3/4 of an inch in thickness or thicker, were prepared by removing the facings from that portion of the plate marked "core, edgewise compression," as indicated in figure 3. Plates that were thinner than 3/4 of an inch did not provide material of sufficient thickness for testing.

Shear.--The modulus of rigidity vas determined by one of three methods, (1) plate shear, (2) torsion pendulum, or (3) frame shear. Balsa, cellular cellulose acetate, and cellular hard rubber were tested by the plate shear method, which is described in paragraphs 33 through 37 of Forest Products Laboratory report 1555.[5] Calcium alginate, pulpboards, British hard rubber, and sponge rubber were tested by the torsion pendulum method; paragraphs 39 through 45 of report 1555.

The frame shear method of test was used to determine the modulus of rigidity for honeycomb structures because the other methods were considered not to be applicable. Figure 4 shows the. dimensions of the assembly of specimen and frame used for this test. Figure 5 shows the assembly with dial located between the heads of a testing machine. The axes of the cells in the honeycomb are perpendicular to the plates and the planes of the corrugated sheets are parallel to the 6-inch dimension. Loads were applied through either a spherical head (fig. 5) or shimmed bearing blocks and thus distributed uniformly across the width of the specimen.

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[5] Tentative Methods of Test for Determining Strength Properties of Core Material for Sandwich Construction. Forest Products Laboratory Report 1555.

During the application of the load, data were taken for use in ;lotting the load-deformation curves. Deformations or shear strains were obtained at equal increments of load to the nearest 0.0002 radian by means of a dial indicator that was mounted on one of the steel plates. This indicator measured the movement of one plate with respect to the other. The modulus of rigidity was determined by calculating the slope of the load-deformation curve according to the following formula:

$$G = \frac{Pc}{awr}$$

where G = the modulus of rigidity associated with shearing strains in the plane parallel to the load and perpendicular to the plane of the steel plates, in pounds per square inch.

P = load, in pounds
c = thickness of the core material between steel plates, in inches
a = length of core material, in inches
w = width of core material, in inches
r = displacement of one plate with respect to the other at load E, in inches.

There is some question as to the accuracy of this method of test. Values that were obtained by this method for some weak materials are 50 percent higher than those obtained by other methods. On the other hand, values for dense core materials obtained by this method agreed with those obtained by other methods. It is believed that the values obtained by the frame shear test of honeycomb core materials are reasonable.

Tests of Facing Material

Compression edgewise.--Load-deformation curves for the 0.005-inch 24 SH aluminum sheet were obtained by testing 1/4- by 1- by 4-inch rectangular specimens that consisted of sheets of aluminum laminated with an adhesive. Stress-strain curves of the aluminum itself were calculated from the stress-strain curves of the laminated specimens by taking into account the stress-strain curve of the bonding agent.

Stress-strain curves for the 24 ST alclad aluminum sheet and glass cloth laminate were obtained by testing dumbbell-shaped specimens (fig. 6), which had an over-all width of 2 inches necked down to 15/16 inch and a length of about 4 inches. Their bearing surfaces were ground smooth and parallel. The specimens were tested between ground surfaces of steel I-shaped plates that provided lateral support for these thin sheets of metal (fig. 7). The distance between the plates was adjusted to provide 0.002-inch clearance between the specimen and the plates. The upper and lower platens were alined by means of a cast-iron frame. Deformation measurements were made by means of a Marten's mirror arrangement with a 1-inch gage length. Tests similar to these in which rectangular brass plates were used for lateral support have been conducted at Langley Memorial Aeronautical Laboratory[6] and found to give satisfactory results within certain limits.

Edgewise compressive data for the papreg and wood facings were obtained by testing rectangular-shaped specimens that were laterally supported at equal intervals along the entire length. The type of apparatus and the testing procedure used are described in ASTM Tentative Standard D805-44T.[7] Yellow-poplar facings that were 0.010 and 0.021 inch thick were too thin for this test and therefore data for these thicknesses were obtained from tests of 0.032-inch facings which matched them.

Shear.- — The modulus of rigidity of aluminum in the plane of the sheet was determined by the torsion pendulum method of test that is described in sections 38 to 43 of Forest Products Laboratory report $555.[5] The moduli of glass cloth laminate and papreg was determined by the plate shear method of test described in sections 33 to 38 of report 1555.

Presentation of Data

The results of tests on the sandwich plates, facing materials, and core materials are shown in tables 1 through 7. The first five tables present the results of tests of sandwich plates. Table 1 presents the results of tests on sandwich constructions having facings of 24 SH aluminum sheet; table 2 having facings of 24 ST alclad aluminum sheet; table 3, glass cloth laminate; table 4, papreg; and table 5, wood. Table 6 presents the properties of the facing materials and table 7 those of the core materials. Typical stress-strain curves for some of these materials are presented in figures 8 and 9.

Tables 1-5, Sandwich Plates

Each table from 1 through 5 presents the results obtained from sandwich constructions having facings of different materials and tested in edgewise compression and flatwise tension. The core materials used in combination with the individual facing materials are listed in each table. The results obtained in flatwise compression tests of sandwich plates are presented in table 7 with other results relating to core materials, The columns and the symbols denoting the properties and the types of failure are common to tables 1 through 5. Each value that is presented is the average of five test specimens.

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[6] NACA Wartime Report L-189 "Investigation of Methods of Supporting Single-Thickness Specimens in a Fixture for Determination of Compressive Stress-Strain Curves." Joseph N. Kotacnchik, Walter Woods, Robert A. Weinberger.

[7] Report of Committee D-7 on Timber, ASTM Tentative Standard D805-44T, 1944 "Proposed Methods of Testing Veneer, Plywood, and Wood-base Laminated Materials."

Columns 1-3.--These columns list the core materials and the thicknesses of the cores and facings. In column 1 each of the core materials is indicated by name. Columns 2 and 3 show the nominal thicknesses of the facings and core materials, respectively.

Columns 4-5.--Column 4 shows the average total thickness of the individual specimens, and column 5 shows the weight of each sandwich construction in pounds per square foot. These values include the thickness and weight of the bonding agent, respectively.

Columns 6-8.--Results of edgewise compression tests of the sandwich constructions are presented in columns 6-7. The loads, P_m, column 6, have been converted to pounds per inch of loaded edge and the strains, column 7, have been converted to unit measure. The values of maximum stress in the facing; material listed in column 8 were computed according to the formula:

$$p_f = \frac{P_m}{2f + \frac{(E_y)_c}{(E_y)_f} c}$$

where P_m = load at failure, pound per linear inch

$(E_y)_c$ = the modulus of elasticity in edgewise compression of the core material in a direction parallel to the load on the sandwich

$(E_y)_f$ = the modulus of elasticity in edgewise compression of the facing material in a direction parallel to the load on the sandwich

c = core thickness in inches

Column 9.--Designations of the types of failure observed are listed in column 9. Six types of failure ware observed and are designated and described as follows: (1) Failure of the facings in compression. Glass cloth, papreg, and wood facings usually failed in this manner. (2) Face wrinkle, apparently good bond. When failure occurred the facing material buckled, wrinkled, formed waves, or popped off the core but the rest of the specimen remained straight and. the bond appeared good. This, type of failure was sometimes difficult to recognize because the amplitude of the waves was very minute and the plane of the failure was often so close to the bond that good and bad bonds were hard to distinguish, (3) Offset failure. This failure consisted of a short crimp near the center of the specimen, the remaining parts of the specimen remaining straight and parallel but not co-linear. The offset consisted of a bending failure in the facings and a shear failure in the core. (4) Face wrinkle, apparently a faulty bond. This failure consisted of a sudden separation of one of the facings from the core and was attributed to inadequate adhesion between them. (5) Failure at the bearing ends. This type of failure occurred at the portion of the facings that were within the clamps, The ends of the facings failed by bending toward the core at the point of contact between the loaded end of the specimen and the bearing block. The two modifications of the test specimens previously described eliminated this type of failure. (6) Failure of cores in compression. When the core supports a substantial portion of the total load its failure is immediately followed by failure of the facings because they are not able to support the total load alone.

Column 10.--Column 10 presents the ratio of the average maximum stress in the facings to a standard stress value. This ratio is equal to p_f/p_y for aluminm and papreg facings, and p_f/p_m for glass cloth laminate and wood facings, where p_y is the yield stress of the facing material at 0.2 percent strain offset and p_m is the maximum stress obtained by edgewise compression tests. The values of p_f are shown in column 8 of tables 1 through 5, and the values of p_y and p_m are shown in columns 6 and 8, respectively, of table 6.

Columns 11 and 12.--Theresults of tests of the sandwich plates in flatwise tension are tabulated in columns 11 and 12. Column 11 presents the maximum tensile strength of the construction in a direction normal to the surface. These values are the strength of the weakest part of the sandwich. Column 12 indicates the predominant type of failure. The types of failure are symbolized by the letters B, C, F, and O. The letter B indicates a failure in the bond; C indicates a failure in the core; F indicates a failure in the facing material, which was in most cases a delamination of the facings; and O indicates a failure that occurred outside the sandwich construction either in the loading block or in the bond between the loading block and the facing of the sandwich.

Table 6. Facing Materials

Table 6 presents data for sone of the properties of the facing materials that were used in the sandwich constructions listed in tables 1 through 5. Each value presented is the average of the results of tests of five specimens. These values were obtained by testing specimens that were representative samples of each thickness of facing material, except those shown for papreg, which were obtained from Forest Products Laboratory report 1319.[2]

Columns 1 and 2.--Thefacing materials and their respective thicknesses are listed in columns 1 and 2.

Column 3.--Column 3 tabulates the specific gravity of the facing materials.

Columns 4 through 7.--Theresults of the tests in edgewise compression are shown in columns 4-7. The Young's modulus of elasticity, $(E_y)_f$, was computed according to the formula:

$$(E_y)_f = \frac{Pg}{bfY}$$

where P is the load in pounds on the specimen, b and f are the width and thickness, respectively, at the net section, and Y is the deformation at load P, measured over a gage length, g. Young's modulus of elasticity and the stress at proportional limit (cols. 4 and 5, respectively), were obtained for all the facing materials. The values of yield stress (col. 6), which is defined as the stress at 0.2 percent strain offset, were obtained for the alminum sheets and the values of maximum stress (col. 7) were obtained for the glass cloth laminate, papreg, and wood facings. In conjunction with these values, typical stress-strain curves for the facing materials are shown in figure 8.

Column 8.--Column 8 presents the values for the modulus of rigidity in shear.

Colums 9 and 10.--Columns 9 and 10 contain cross references from table 6 to tables 1 through 5. Column 9 contains the number of the reference table. Column 10 designates the core material of the particular sandwich construction referred to.

Table 7, Core Materials

Table 7 presents the results obtained from the core materials tested in flatwise and edgewise compression and transverse shear. It should be noted that the individual values in this table for the nodulus of elasticity in flatwise compression were obtained either from the sandwich specimens or the core specimens. The core materials and their respective thicknesses are listed and cross referenced in the same sequence as they were listed in tables 1 through 5. Each value is the average obtained from five specimens.

Column 1.--Column 1 lists the core materials that were used in the construction of the sandwich plates. The orientation of the core materials in the sandwich plates is indicated.

Column 2.--Incolumn 2 the average specific gravity is listed for each core material.

Columns 3 and 4.--TheYoung's moduli of elasticity that were determined by the compression tests in the flatwise direction are listed in columns 3 and 4. These values were computed according to the formula

$$(E_z)_c = \frac{Pg}{abY}$$

in which P = the load on the specimen in pounds at deformation Y in inches, g = the gage length in inches, and ab = the cross-sectional dimensions in inches. In column 3, the values were determined from the deformation data that were obtained by means of strain gages attached to the sides of the specimens; in column 4 the values were determined from deformation data obtained by measuring the deformations between heads. The values obtained by the latter method are lower but more consistent than those obtained by the strain-gage method.

Columns 5 through 9.--The data that were obtained from tests of specimens in edgewise compression are tabulated in columns 5-8. Column 5 presents values of Young's modulus. Columns 6 and 7 present the values of the proportional limit stress and the maximum stress, respectively. Sone core materials, like balsa, loaded in the radial or tangential direction or a honeycomb structure loaded in a direction-perpendicular to the length of the cells may not reach a maximum load until they have been compressed to a solid mass. The maximum stress for these materials was defined as the stress at which there was very small increase in stress for a very large increase in deformation. Column 8 presents the values of the strains that were recorded at the maximum stress. In conjunction with the data in these columns, typical stress-strain curves for these materials are shown in figure 9.

Column 9.--The values that were obtained for the modulus of rigidity by tho methods previously described are tabulated in column 9.

Columns 10 and 11.--Columns 10 and 11 contain cross references from table 7 to tables 1 through 5. Column 10 contains the number of the table referred to and the thickness of the face of the particular sandwich construction in that table. Column 11 contains the thicknesses of the cores of the particular sandwich construction referred to.

Table 1.--Tension and compression strength of flat sandwich specimens with aluminum facings (24SH aluminum sheet)

Construction			Sandwich properties								
Core material	Nominal thickness		Total thickness	Weight of sandwich	Edgewise compression					Flatwise tension	
	Face	Core			Maximum values			Type of failure[1]	Ratio of maximum stress in facing to yield stress of facing material	Tensile strength	Type of failure[2]
					Load	Strain	Stress in facing				
	f	c	h	wt.	P_m	ϵ_m	p_f			p_n	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	In.	In.	In.	Lb. per sq. ft.	Lb. per in. of edge	In. per in.	Lb. per sq. in.			Lb. per sq. in.	
Balsa (E.G.)	0.005	1/4	0.255	0.351	362	0.0097	34,600	4	0.700	932	C
		1/2	.506	.459	402	.0083	37,200	4	.752	1,101	C
		3/4	.769	.597	282	.0042	25,730	4	.520	697	B
		1	1.019	.647	270	.0053	22,940	4	.464	628	C
Cellular hard rubber	.005	1/4	.267	.393	278	.0040	26,600	2	.538	324	C
		1/2	.502	.516	329	.0050	31,400	2	.634	301	C
		3/4	.771	.680	380	.0055	35,440	2	.716	329	C
		1	1.019	.901	459	.0069	41,550	2	.840	334	C
Cellular cellulose acetate	.005	1/4	.249	.334	213	.0029	20,450	2	.413	320	C
		1/2	.501	.485	244	.0032	22,400	2	.453	332	C
		3/4	.726	.675	294	.0035	26,250	2	.530	225	C
		1	.980	.796	284	.0037	23,920	4	.483	197	B

[1] Type of failure (compression): (1) Failure of facings in compression; (2) face wrinkle, apparently good bond; (3) offset failure; (4) face wrinkle, failure at bond; (5) failure at bearing ends; and (6) failure of cores in compression.

[2] Type of failure (tension): (B) Predominant bond failure; (C) predominant core failure; (F) delamination of facing material; and (O) failure occured outside sandwich material.

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Table 2.--Tension and compression strength of flat sandwich specimens with aluminum facings (24ST alclad sheet)

Construction			Sandwich properties								
Core material	Nominal thickness		Total thickness	Weight of sandwich	Edgewise compression					Flatwise tension	
	Face	Core			Maximum values			Type of failure[1]	Ratio of maximum stress in facing to yield stress of facing material	Tensile strength	Type of failure[2]
					Load	Strain	Stress in facing				
	f	c	h	wt.	P_m	ϵ_m	p_f			P_b	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	In.	In.	In.	Lb. per sq. ft.	Lb. per in. of edge	In. per in.	Lb. per sq. in.			Lb. per sq. in.	
Balsa (E.G.)	0.0125	1/4	0.282	0.657	1,173	0.0110	46,150	4	1.050	1,004	O
		1/2	.527	.804	1,168	.0094	45,400	4	1.030	400	B
		5/8	.645	.763	919	.0046	35,950	4	.818	524	B
		3/4	.778	.926	1,081	.0066	41,750	4	.950	715	O
		1	1.030	1.333	1,059	.0062	40,450	4	.920	1,063	O
		1-1/4	1.271	1.117	839	.0039	31,450	4	.715	751	O
		1-7/8	1.869	1.309	594	.0024	22,650	4	.515	960	O
		2-1/2	2.470	1.696	478	.0021	17,760	4	.404	882	B
	.0185	1/4	.297	.831	2,166	.0132	58,000	3	1.397	514	O
		1/2	.544	.995	2,197	.0329	58,000	3	1.397	848	O
		3/4	.788	1.215	1,914	.0064	51,800	2	1.249	506	O
		1	1.035	1.105	1,641	.0075	42,900	4	1.034	585	O
	.0200	7/16	.448	....	2,803	.0586	70,000	3	1.686	745	O
		1/2	.567	....	2,574	.0430	64,400	3	1.550	648	O
	.0320	1/4	.325	1.200	3,178	.0116	49,620	3	1.181	1,188	C
		1/2	.468	1.240	3,192	.0132	49,680	5	1.183	1,149	C
		3/4	.621	1.429	3,856	.0346	59,980	3	1.428	1,254	C
		1	1.068	1.558	4,184	.0440	64,550	3	1.536	1,256	C
Calcium alginate	.0200	1/2	.574	....	1,696	.0060	41,100	2	.990	108	C
		3/4	.810	....	1,220	.0032	28,900	2	.697	108	C
	.0320	1/2	.595	....	2,867	.0089	43,800	2	1.043	108	C
Cellular cellulose acetate	.0125	1/4	.278	.612	1,111	.0084	45,300	3	1.030	299	C
		1/2	.514	.789	1,095	.0066	42,250	2	.960	....	....
		5/8	.568	.848	689	.0032	27,700	4	.630	128	O
		3/4	.780	.978	972	.0045	37,200	4	.843	265	C
		1	1.019	1.132	1,107	.0054	42,100	2	.957	261	C
		1-1/4	1.209	1.322	1,043	.0055	42,000	2	.954	253	C
		1-7/8	1.844	1.619	848	.0037	34,100	5	.776	58	O
		2-1/2	2.455	2.050	957	.0037	38,500	2	.875	89	O
	.0185	1/4	.280	.802	1,565	.0045	41,950	3	1.010	308	C
		1/2	.547	.987	1,454	.0053	38,210	5	.920	75	B
		3/4	.782	1.204	1,446	.0059	37,410	2	.902	257	C
		1	1.030	1.333	1,874	.0053	48,600	2	1.170	257	C
	.0320	1/4	.311	1.101	2,281	.0050	35,500	3	.846	174	B
		1/2	.557	1.194	2,244	.0047	34,800	2	.828	104	B
		3/4	.887	1.418	2,054	.0043	31,700	2	.754	109	B
		1	1.043	1.542	2,505	.0050	38,300	2	.912	108	B
Honeycomb glass cloth[3]	.0200	1/4	0.283	....	1,120	....	28,000	3	0.675	....	....
		1/2	.547	....	1,386	....	34,600	2	.834	....	....
Honeycomb paper[3]	.0200	1/4	.295	....	1,785	....	44,600	3	1.075	....	....
		1/2	.550	....	1,072	....	26,800	4	.646	....	....
Cellular hard rubber	.0125	1/4	.297	0.677	1,013	0.0064	40,000	3	.909	243	C
		1/2	.537	.848	1,175	.0096	45,850	2	1.042	269	C
		5/8	.664	.840	457	.0021	17,900	4	.407	230	C
		3/4	.790	.951	994	.0058	38,600	2	.878	263	C
		1	1.046	1.167	990	.0039	33,700	4	.766	276	C
		1-1/4	1.277	1.217	727	.0034	27,900	4	.634	227	C
		1-7/8	1.926	1.730	890	.0041	34,200	4	.777	206	C
		2-1/2	2.548	2.247	819	.0034	30,130	4	.685	211	C
		[3]2-1/2	2.405	....	1,073	.0049	42,900	2	.975	....	....
	.0185	1/4	.308	.831	1,213	.0059	32,500	3	.783	213	C
		1/2	.542	.944	1,549	.0084	41,150	2	.992	171	C
		3/4	.800	1.097	1,440	.0050	38,300	5	.923	286	C
		1	1.045	1.309	1,473	.0052	39,000	2	.940	324	C
	.0320	1/4	.325	1.242	2,156	.0040	33,600	3	.800	130	C
		1/2	.580	1.398	2,096	.0047	32,600	3	.776	143	C
		3/4	.826	1.536	1,783	.0032	27,600	4	.657	90	C
		1	1.081	1.718	1,866	.0033	28,800	4	.686	....	....
British hard rubber[3]	.0125	2-1/2	2.386	....	491	.0019	18,700	4	.425	....	....
Pulp board (30 percent resin)[3]	.0125	3/4	.854	....	511	.0017	17,400	2	.396	....	....
Sponge rubber (special)[4]	.0082	7/16	.427	....	166	....	10,130	2	.220	....	....
		7/8	.822	....	281	....	17,100	2	.328	....	....
		1-1/4	1.240	....	325	....	19,640	2	.427	....	....
		1-5/8	1.646	....	310	....	18,840	2	.409	....	....
		2	2.037	....	239	....	14,370	2	.312	....	....
Spruce plywood	.0200	3/16	.236	....	2,567	.0040	33,300	6	.802	....	....
		3/8	.437	....	3,199	.0051	36,300	6	.875	....	....
		3/4	.825	....	4,870	.0059	43,300	6	1.044	....	....

[1]Type of failure (compression): (1) Failure of facings in compression; (2) face wrinkle, apparently good bond; (3) offset failure; (4) face wrinkle, failure at bond; (5) failure at bearing ends; and (6) failure of cores in compression.

[2]Type of failure (tension): (B) Predominant bond failure; (C) predominant core failure; (F) delamination of facing material; and (O) failure occured outside sandwich material.

[3]Sandwich plates fabricated with wooden inserts.

[4]Sandwich plates fabricated with plaster disks.

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Table 3.--Tension and compression strength of flat sandwich specimens with facings of glass cloth laminate (cross-laminated)

Construction			Sandwich properties								
Core material	Nominal thickness		Total thickness	Weight of sandwich	Edgewise compression					Flatwise tension	
	Face	Core			Maximum values			Type of failure[1]	Ratio of maximum stress in facing: stress of facing material	Tensile strength	Type of failure[2]
					Load	Strain	Stress in facing				
	f	c	h	wt.	P_m	ϵ_m	P_f			P_n	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	In.	In.	In.	Lb. per sq. ft.	Lb. per in. of edge	In. per in.	Lb. per sq. in.			Lb. per sq. in.	
Balsa (E.G.)	0.009 (2-ply)	1/4	0.280	0.551	349	0.0122	15,800	1	[3]0.797	660	F
		1/2	.515	.792	362	.0137	17,760	1	[3].896	622	F
		3/4	.762	1.112	311	.0163	14,850	1	[3].749	649	F
		1	1.020	1.038	276	.0085	13,480	1	[3].679	619	F
	.016 (4-ply)	1/4	.292	.639	677	.0102	17,170	1	.866	456	O
		1/2	.529	.811	583	.0100	16,000	1	.806	512	F
		3/4	.773	1.233	580	.0088	17,360	1	.875	632	F
		1	1.023	1.218	526	.0081	16,290	1	.820	538	F
	.032 (8-ply)	1/4	.316	.866	1,308	.0109	18,240	1	.876	610	F
		1/2	.564	1.124	1,360	.0113	19,600	1	.942	657	F
		3/4	.810	1.580	1,442	.0111	21,000	1	1.010	697	F
		1	1.051	1.594	1,180	.0086	20,980	1	1.008	215	F
	.044 (16-ply)	1/4	.337	1.125	1,918	.0097	21,930	1	.998	887	F
		1/2	.585	1.121	1,837	.0085	20,650	1	.938	....	....
		3/4	.837	1.228	2,062	.0088	22,560	1	1.025		
		1	1.080	1.472	2,062	.0088	23,180	1	1.053	712	F
Cellular hard rubber	.010 (3-ply)	1/4	.269	.322	223	.0050	10,250	2	.729	211	C
		1/2	.511	.447	199	.0043	8,770	4	.624	116	B
		3/4	.790	.654	135	.0027	5,975	4	.425	87	B
		1	1.023	.699	177	.0043	5,980	2	.426	123	B
	.019 (6-ply)	1/4	.270	.474	659	.0072	17,820	1	.978	233	C
		1/2	.540	.665	543	.0057	14,190	4	.778	79	B
		3/4	.822	.785	608	.0062	15,550	1	.854	138	B
		1	1.037	.933	685	.0067	17,200	2	.944	131	B
	.030 (10-ply)	1/4	.306	.694	1,119	.0077	18,520	3	.834	234	C
		1/2	.565	.871	990	.0069	15,980	1	.633	234	C
		3/4	.826	.984	1,136	.0072	19,050	1	.755	197	C
		1	.973	1.163	1,271	.0075	20,750	1	.822	220	C
Cellular cellulose acetate	0.010 (3-ply)	1/4	0.269	0.297	239	....	11,480	1	1.274	330	C
		1/2	.509	.425	272	0.0057	12,370	1	1.374	234	B
		3/4	.747	.601	377	.0068	14,640	1	1.625	270	C
		1	1.006	.801	206	.0045	7,200	4	.800	193	B
	.019 (6-ply)	1/4	.282	.463	587	.0039	15,950	1	.940	362	C
		1/2	.530	.619	773	.0077	18,640	1	1.100	371	C
		3/4	.756	.832	653	.0072	16,100	1	.949	244	C
		1	1.020	1.012	671	.0069	15,880	1	.936	204	B
	.030 (10-ply)	1/4	.303	.686	1,271	.0086	21,000	1	.874	356	C
		1/2	.553	.807	1,341	.0087	21,700	1	.904	252	C
		3/4	.771	1.023	1,177	.0076	18,300	1	.762	243	C
		1	1.042	1.226	1,231	.0078	19,120	1	.796	176	C
	.044 (16-ply)	1/4	.335	.980	1,708	.0078	19,410	1	.862	314	C
		1/2	.582	1.134	1,718	.0079	20,000	1	.889	....	....
		3/4	.829	1.377	2,165	.0089	22,750	1	1.011	255	C
		1	1.079	1.538	2,264	.0094	22,870	1	1.016	287	C
Honeycomb glass cloth	.010 (3-ply)	1/4	.272	.452	262	.0059	13,100	1	[4].932	....	....
		1/2	.501	.562	253	.0053	12,650	1	[4].900	....	....
		3/4	.759	.891	237	.0047	11,850	1	[4].843	....	....
		1	1.028	.980	249	.0050	12,450	1	[4].886	....	....
	.017 (6-ply)	1/4	.243	.450	490	.0058	14,410	1	[4]1.026	....	....
		1/2	.503	.598	436	.0054	14,810	1	[4]1.055	....	....
		3/4	.760	.755	402	.0047	12,550	1	[4].893	303	B
		1	.990	.862	429	.0054	13,400	1	[4].954	267	B
British hard rubber[5]	.013 (4-ply)	1-1/2	1.538	....	471	.0068	12,100	1	[4].862	....	....

[1]Type of failure (compression): (1) Failure of facings in compression; (2) face wrinkle, apparently good bond; (3) offset failure; (4) face wrinkle, failure at bond; (5) failure at bearing ends; and (6) failure of cores in compression.

[2]Type of failure (tension): (B) Predominant bond failure; (C) predominant core failure; (F) delamination of facing material; and (O) failure occurred outside sandwich material.

[3]19,840 pounds per square inch used as maximum stress of facing material from test of 0.016-inch material.

[4]14,050 pounds per square inch used as maximum stress of facing material from test of 0.010-inch material.

[5]Sandwich plate fabricated with wooden inserts.

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Table 4.--Tension and compression strength of flat sandwich specimens with papreg facings (cross-laminated)

Construction: Core material	Nominal thickness: Face	Nominal thickness: Core	Total thickness	Weight of sandwich	Edgewise compression, Maximum values: Load	Strain	Stress in facing	Type of failure[1]	Ratio of maximum stress in facing to yield stress of facing material	Flatwise tension: Tensile strength	Type of failure[2]
	f	c	h	wt.	P_m	ϵ_m	p_f			p_n	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	In.	In.	In.	Lb. per sq. ft.	Lb. per in. of edge	In. per in.	Lb. per sq. in.			Lb. per sq. in.	
Balsa (loaded parallel to grain)	0.009	7/8	0.908	1.020	3,030	0.0042	8,580	6	0.732	204	C
	.027	5/8	.690	1.030	2,428	.0043	8,210	6	.700	186	C
	.042	3/8	.450	....	2,050	.0083	9,190	6	.785	187	O
Balsa (loaded flat, perpendicular to grain)	.009	7/8	.906	1.030	359	.0116	10,680	1	.913	140	C
	.025	5/8	.677	1.020	864	.0141	14,250	1	1.216	162	C
	.042	3/8	.452	....	1,103	.0109	12,200	1	1.043	159	C
Balsa (E.G.)	.009	7/8	.870	1.140	446	.0347	18,200	1	1.554	435	B
	.027	5/8	.684	1.140	1,226	.0279	20,500	1	1.750	525	F
	.042	3/8	.492	1.175	1,696	.0120	19,250	1	1.045	737	F
Calcium alginate	.009	1/2	.556	.508	342	.0105	14,150	1	1.210	108	C
	.018	1/2	.577	.645	624	.0130	14,780	1	1.263	....	....
	.026	3/8	.467	....	977	.0175	17,120	1	1.462	....	....
Pulpboard	.022	3/4	.742	1.030	849	.0115	15,550	1	1.330	22	C
	.022	3/8	.414	.752	674	.0096	13,210	1	1.130	35	C
	.044	3/8	.462	1.075	1,090	.0070	11,350	1	.980	40	C
	.066	3/8	.502	1.500	1,704	.0078	12,050	1	1.030	40	C

[1]Type of failure (compression): (1) Failure of facings in compression; (2) face wrinkle, apparently good bond; (3) offset failure; (4) face wrinkle, failure at bond; (5) failure at bearing ends; and (6) failure of cores in compression.

[2]Type of failure (tension): (B) Predominant bond failure; (C) predominant core failure; (F) delamination of facing material; and (O) failure occured outside sandwich material.

Table 5.--Tension and compression strength of flat sandwich specimens with facings of wood veneer

Construction: Core material	Nominal thickness: Face	Nominal thickness: Core	Total thickness	Weight of sandwich	Edgewise compression, Maximum values: Load	Strain	Stress in facing	Type of failure[1]	Ratio of maximum stress in facing to maximum stress of facing material	Flatwise tension: Tensile strength	Type of failure[2]
	f	c	h	wt.	P_m	ϵ_m	p_f			p_n	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	In.	In.	In.	Lb. per sq. ft.	Lb. per in. of edge	In. per in.	Lb. per sq. in.			Lb. per sq. in.	
Laminated yellow-poplar and pulpboard (48.3 percent resin)	0.010	3/8	0.341		243	0.0097	9,400	1	1.170	20	C
	.021	3/8	.387		355	.0092	7,560	1	.941	21	C
	.032	3/8	.374		472	.0062	6,810	1	.849	17	C
	.042	3/8	.395		593	.0064	6,620	1	.802	17	C
	.051	3/8	.444		813	.0059	7,540	1	.965	27	C
	.064	3/8	.469		986	.0083	7,430	1	.910	32	C
	.071	3/8	.501		1,094	.0080	7,390	1	.905	29	C
	.083	3/8	.508		1,261	.0069	7,360	1	.903	22	C
	.095	3/8	.508		1,146	.0062	5,850	1	.922	20	C
	.102	3/8	.529		1,345	.0054	6,440	1	.961	19	C
Laminated yellow-poplar and pulpboard (17.3 percent resin)	.051	3/8	.499		610	.0037	5,870	1	.780	11	C
(27.8 percent resin)	.051	3/8	.503		694	.0049	6,600	1	.859	13	C
(43.7 percent resin)	.051	3/8	.503		832	.0074	7,760	1	1.004	29	C
(48.3 percent resin)	.051	3/8	.508		832	.0093	7,780	1	1.025	25	C
(57.2 percent resin)	.051	3/8	.496		954	.0120	8,670	1	1.117	53	C
(70.0 percent resin)	.052	3/8	.479		1,014	.0128	8,760	1	1.100	85	C
Spruce plywood and balsa (loaded parallel to grain)	.074	3/4	.882		1,757	.0055	3,080	6	1.145	79	C
Spruce plywood and balsa (loaded flat, perpendicular to grain)	.070	3/4	.895		654	.0077	4,120	1	1.155	124	C
Spruce plywood and calcium alginate	.072	1-1/8	1.252		841	.0097	4,630	1	1.486	108	C
Spruce plywood and cellular hard rubber	.07[illegible]	3/4	.947		528	.0057	3,270	2	.989	81	C

[1]Type of failure (compression): (1) Failure of facings in compression; (2) face wrinkle, apparently good bond; (3) offset failure; (4) face wrinkle, failure at bond; (5) failure at bearing ends; and (6) failure of cores in compression.

[2]Type of failure (tension): (B) Predominant bond failure; (C) predominant core failure; (F) delamination of facing material; and (O) failure occured outside sandwich material

Table 6.--Mechanical properties of facing materials used in sandwich construction

Material	Thickness	Property: Specific gravity	Property: Compression: Modulus of elasticity	Property: Compression: Stress at proportional limit	Property: Compression: Yield stress at 2 percent offset	Property: Compression: Maximum stress	Property: Shear: Modulus of rigidity	Cross reference to tables 1-5: Tables	Cross reference to tables 1-5: Cores
	f		$(E_y)_f$	p_{pl}	p_y	p_m	μ_{xy}		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	In.		1,000 lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	1,000 lb. per in.		
24SH aluminum sheet	0.0050	2.78	11,370	38,200	49,500			Table 1	
24ST alclad aluminum	.0082	2.78	9,500	28,000	46,000			Table 2	
	.0125	2.78	9,540	28,500	44,000		[1]3,800	....do....	
	.0185	2.78	9,490	31,060	41,500			....do....	
	.0200	2.78	9,490	31,060	41,500			....do....	
	.0320	2.78	9,500	27,500	42,000			....do....	
Glass cloth laminate	.016	1.75	1,796	17,540		19,840	[2] 387	Table 3	Balsa cores
	.032	1.75	1,959	14,850		20,800		....do....	.......do
	.044	1.78	2,500	....		22,000		....do....	.......do
	.010	1.78	2,170	13,320		14,050		....do....	Hycar cores
	.019	1.78	2,195	15,860		18,210		....do....	.......do
	.030	1.78	2,285	22,080		25,240		....do....	.......do
	.010	1.78	1,976	8,810		9,010		....do....	Cellular cellulose acetate
	.019	1.78	2,210	14,840		16,950		....do....	.......do
	.030	1.78	2,304	21,480		24,010		....do....	.......do
	.044	1.78	2,400	....		22,500		....do....	.......do
Papreg (cross-laminated)	1/8	1.40	2,370	5,000	11,700	19,150	887	Table 4	(From 1319B)
Yellow-poplar (laminate)	.010	.605	1,778	4,210		8,030		Table 5	
	.021	.605	1,778	4,210		8,030		....do....	
	.032	.605	1,778	4,210		8,030		....do....	
	.042	.621	1,640	4,370		8,250		....do....	
	.051	.570	1,917	4,050		7,810		....do....	
	.064	.680	2,051	4,900		8,170		....do....	
	.071	.600	1,815	4,900		8,160		....do....	
	.083	.670	1,931	4,820		8,150		....do....	
	.095	.520	1,619	3,450		6,340		....do....	
	.102	.580	1,798	4,110		6,700		....do....	
	.051	.570	1,799	5,240		7,680		....do....	
	.051	.570	1,731	4,920		7,590		....do....	
	.051	.570	1,728	4,500		7,520		....do....	
	.051	.570	1,858	4,900		7,680		....do....	
	.051	.570	1,830	5,120		7,730		....do....	
	.051	.570	1,737	5,280		7,590		....do....	
	.051	.570	1,846	5,640		7,750		....do....	
	.051	.570	1,820	5,880		7,960		....do....	
Spruce plywood (1/48 + 1/32 + 1/48)	.074	.420	834	2,320		2,690		....do....	
	.070	.420	1,027	3,250		3,560		....do....	
	.072	.420	886	2,790		3,110		....do....	
	.072	.420	895	3,020		3,310		....do....	

[1]Value applicable to all thicknesses of aluminum.

[2]Value applicable to all thicknesses of glass cloth.

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Table 7.--Mechanical properties of core materials used in sandwich construction

Material	Property: Specific gravity	Property: Compression: Flatwise: Modulus of elasticity (1/4-inch gage length)	Property: Compression: Flatwise: Modulus of elasticity (Dials between heads)	Property: Compression: Edgewise: Modulus of elasticity	Property: Compression: Edgewise: Stress at proportional limit	Property: Compression: Edgewise: Maximum stress	Property: Compression: Edgewise: Strain at maximum stress	Property: Shear: Perpendicular to face: Modulus of rigidity	Cross reference to tables 1-5: Table No. and thickness of facings	Cross reference to tables 1-5: Thickness of core
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
		1,000 p.s.i.	1,000 p.s.i.	1,000 p.s.i.	P.s.i.	P.s.i.	Inch per inch	1,000 p.s.i.	In.	In.
Balsa (E.G.)	0.095	...	68.6	...	...	...	...	[1]15.0	Table 1	1/4
	to	216.7	118.8	...	...	...	...		...do...	1/2
	.145	320.4	121.6	3.53	21.5	48.7	0.0284		...do...	3/4
		424.5	124.0	3.32	20.7	49.3	.0364		...do...	1
		...	79.5	...	...	...	...		Table 2 (0.125)	1/4
		238.2	107.9	...	...	...	...			1/2
		509.1	84.1	8.78	36.5	74.3	.0481			5/8
		446.4	151.2	9.64	35.2	72.9	.0267			3/4
		[illegible]12.2	312.9	7.95	40.1	79.9	.0224			1
		[2]396.3	223.6	12.90	38.1	74.3	.0139			1-1/4
		[1]131.0	139.8	4.19	26.3	53.7	.0364			1-7/8
		[2]276.5	208.3	7.78	34.2	72.7	.0361			2-1/2
		...	68.1	...	...	...	...		Table 2 (0.0185)	1/4
		299.8	128.1	...	...	...	...			1/2
		415.9	161.0	10.47	60.3	116.1	.0274			3/4
		387.1	82.5	5.33	28.2	67.8	.0339			1
		1,075.0	372.0	...	...	121.0	.0200		Table 2 (0.0200)	7/16
		847.0	370.0	...	...	130.0	.0200			1/2
		...	160.1	...	...	...	...		Table 2 (0.0320)	1/4
		452.2	152.5	...	...	...	...			1/2
		381.0	197.5	4.30	30.3	57.6	.0255			3/4
		390.6	166.0	4.30	30.9	61.4	.0300			1
		...	173.6	...	...	...	...		Table 3 (0.009)	1/4
		506.8	249.0	10.15	37.2	80.3	.0215			1/2
		935.0	485.3	11.80	51.1	113.3	.0234			3/4
		786.8	347.9	12.65	51.7	99.7	.0212			1
		...	79.2	...	...	...	...		Table 3 (0.016)	1/4
		535.4	212.2	7.95	42.2	88.3	.250			1/2
		1,071.5	503.8	7.79	52.5	126.3	.0381			3/4
		640.4	354.2	8.08	38.3	95.2	.0348			1
		...	82.8	...	...	...	...		Table 3 (0.032)	1/4
		799.3	197.0	10.52	49.6	107.1	...			1/2
		1,146.6	427.1	6.85	52.6	119.7	.0455			3/4
		604.0	386.9	7.71	40.3	107.4	.0285			1
		...	74.8	...	...	...	...		Table 3 (0.044)	1/4
		161.6	74.6	...	...	...	...			1/2
		691.2	134.0	13.3	32.0	70.9	.0128			3/4
		488.9	182.2	4.0	26.6	55.6	.0350			1
Balsa (loaded parallel to grain)	.200	36.6	30.3	[4]900.0	[4]1,700	2,490	.0037	[4]40.0	Table 4 (0.009)	7/8
		26.6	14.4	[4]900.0	[4]1,800	2,770	.0039	[4]40.0	(.027)	5/8
		30.3	11.0	[4]900.0	[4]1,800	2,550	.0042	[4]40.0	(.042)	3/8
Balsa (loaded flat, perpendicular to grain)	.200	36.6	22.0	42.0	82.0	189	.0400	[4]4.8	Table 4 (0.009)	7/8
		15.9	11.6	40.1	60.0	134	.0400	[4]4.8	(.025)	5/8
		19.9	8.7	41.8	112.0	290	.0400	[4]4.8	(.042)	3/8
Balsa (E.G.)	.210	762.6	352.4	18.0	94.4	183	.0400	[4]40.0	Table 4 (0.009)	7/8
		1,161.0	312.3	22.0	110.0	207	.0400	[4]40.0	(.027)	5/8
		1,550.0	233.0	24.3	97.5	197	.0400	[4]40.0	(.042)	3/8
Balsa (loaded parallel to grain)	.14	9.3	7.7	[4]480.0	[4]1,000	1,550	.0052	[4]40.0	Table 5 (0.074)	3/4
Balsa (loaded flat, perpendicular to grain)	.14	10.2	8.6	25.5	40.0	84	.0400	[4]4.8	Table 5 (0.072)	3/4
Calcium alginate	0.11	22.4	13.1	[5]30	[5]85	[5]245	[5]0.0160	[5]16.7	Table 2 (0.020)	1/2
		38.8	15.4						(.032)	3/4
		31.7	14.1							1/2
		19.2	14.8						Table 4 (0.009)	1/2
		36.8	11.3						(.018)	1/2
		28.7	11.6						(.026)	3/8
		21.9	14.4						Table 5 (0.072)	3/4

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Table 7.--Mechanical properties of core materials used in sandwich construction (Continued)

Material	Specific gravity	Compression: Flatwise: Modulus of elasticity: (1/4-inch gage length)	Compression: Flatwise: Modulus of elasticity: (Dials between heads)	Compression: Edgewise: Modulus of elasticity	Compression: Edgewise: Stress at proportional limit	Compression: Edgewise: Maximum stress	Compression: Edgewise: Strain at maximum stress	Shear: Perpendicular to face: Modulus of rigidity	Cross reference to tables 1-5: Table No. and thickness of facings	Cross reference to tables 1-5: Thickness of core
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
		1,000 p.s.i.	1,000 p.s.i.	1,000 p.s.i.	P.s.i.	P.s.i.	Inch per inch	1,000 p.s.i.	In.	In.
Cellular cellulose acetate (3 percent glass fibers)	.100	...	9.8	...	...	...	...	[6]3.5	Table 1 (0.005)	1/4
		28.8	16.6	...	...	...	...			1/2
		42.2	14.9	7.50	52.5	117.4	.0391			3/4
		67.2	21.4	14.79	65.5	150.5	.0230			1
		...	5.5	...	...	...	...		Table 2 (0.0125)	1/4
		9.6	6.0	...	...	...	...			1/2
		54.1	10.6	...	...	...	...			5/8
		35.5	10.9	8.35	73.4	145.1	.0330			3/4
		72.5	12.4	10.37	70.7	139.9	.0382			1
		[2]37.1	14.4	13.37	78.4	154.3	.0573			1-1/4
		[3]22.1	17.3	13.78	60.9	138.6	.0315			1-7/8
		[2]22.2	16.5	14.65	63.4	147.7	.0277			2-1/2
		...	5.5	...	...	...	...		Table 2 (0.0185)	1/4
		26.0	7.4	...	...	...	...			1/2
		30.5	6.7	18.69	75.4	182.3	.0280			3/4
		20.0	6.5	12.77	58.0	140.1	.0430			1
		...	19.5	...	...	...	...		Table 2 (0.032)	1/4
		24.1	13.9	...	...	...	...			1/2
		28.7	14.6	16.54	83.5	204.7	.0248			3/4
		32.4	20.9	15.06	82.2	170.7	.0303			1
		...	14.3	...	...	...	...		Table 3 (0.010)	1/4
		45.8	17.4	...	...	...	...			1/2
		70.5	19.3	9.75	64.7	163.1	.0334			3/4
		23.8	16.5	12.52	74.3	150.0	.0285			1
		...	19.0	...	...	...	...		Table 3 (0.019)	1/4
		25.6	18.3	...	...	...	...			1/2
		27.0	18.4	13.67	72.8	161.5	.0255			3/4
		42.5	17.7	10.47	62.1	149.9	.0452			1
		...	15.1	...	...	...	...		Table 3 (0.030)	1/4
		28.3	17.8	...	...	...	...			1/2
		43.5	18.9	15.59	66.4	171.0	.0270			3/4
		38.4	18.3	11.00	65.8	152.0	.0423			1
		...	14.9	...	...	...	...		Table 3 (0.044)	1/4
		107.3	17.1	...	...	...	...			1/2
		95.6	14.3	15.7	75.8	182.3	.0200			3/4
		37.4	19.2	13.7	66.3	140.8	.0160			1
Honeycomb glass cloth	.10	110.0	47.0	.035	.9	1.2	.0300	3.8	Tables 2 and 3	
Honeycomb paper	.10	[7]72.5	...	.110	3.0	9.0	...	11.6	Table 2	
Cellular hard rubber	0.100	...	11.3	...	...	...	...	[8]3.9	Table 1 (0.005)	1/4
		36.0	14.4	...	...	...	...			1/2
		37.6	15.9	5.85	45.7	108.6	0.0322			3/4
		46.3	15.5	6.55	53.7	134.5	.0430			1
		...	10.1	...	...	...	...		Table 2 (0.0125)	1/4
		26.8	12.2	...	...	...	...			1/2
		22.1	15.0	9.28	66.0	136.9	.0235			5/8
		31.6	12.3	4.52	44.6	91.5	.0407			3/4
		32.9	14.6	9.52	73.6	161.2	.0251			1
		[2]19.1	13.0	8.47	56.8	138.2	.0270			1-1/4
		[3]14.9	12.8	5.30	40.6	106.1	.0400			1-7/8
		[2]14.7	13.0	8.50	62.7	145.7	.0331			2-1/2
		...	7.2	...	...	...	...		Table 2 (0.0185)	1/4
		39.0	10.4	...	...	...	...			1/2
		29.5	13.1	5.28	48.3	90.5	.0254			3/4
		28.3	15.7	5.81	48.5	117.9	.0386			1
		...	3.5	...	...	...	...		Table 2 (0.032)	1/4
		41.8	16.1	...	...	...	...			1/2
		32.4	15.3	8.66	64.2	122.5	.0320			3/4
		23.4	16.3	13.17	84.6	171.5	.0171			1
		...	14.4	...	...	...	...		Table 3 (0.010)	1/4
		19.7	7.8	...	...	...	...			1/2
		31.3	14.9	5.51	50.1	115.4	.0429			3/4
		23.0	10.0	2.86	27.3	55.7	.0428			1

Table 7.--Mechanical properties of core materials used in sandwich construction (Continued)

Material	Property: Specific gravity	Compression: Flatwise: Modulus of elasticity (1/4-inch gage length)	Compression: Flatwise: Modulus of elasticity (Dials between heads)	Compression: Edgewise: Modulus of elasticity	Compression: Edgewise: Stress at proportional limit	Compression: Edgewise: Maximum stress	Compression: Edgewise: Strain at maximum stress	Shear: Perpendicular to face: Modulus of rigidity	Cross reference to tables 1-5: Table No. and thickness of facings	Cross reference to tables 1-5: Thickness of core
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
		1,000 p.s.i.	1,000 p.s.i.	1,000 p.s.i.	P.s.i.	P.s.i.	Inch per inch	1,000 p.s.i.	In.	In.
Cellular hard rubber		...	10.2	...	...	...	...		Table 3	1/4
		21.6	6.3	...	...	...	...		(0.019)	1/2
		22.5	12.4	5.87	55.9	111.2	.0352			3/4
		31.9	15.5	6.95	53.7	118.8	.0286			1
		...	13.9	...	...	...	...		Table 3	1/4
		27.2	13.0	...	...	...	...		(0.044)	1/2
		29.0	14.7	6.06	50.2	107.7	.0353			3/4
		16.0	11.7	7.62	58.2	119.5	.0262			1
		13.9	2.2	...	...	62.0	.0183		Table 5	
British hard rubber	.13	8.2	7.3	[9]18.90	[9]90.0	[9]250.0	[9].0180	[9]3.4	Tables 2 and 3	
Pulpboard (30 percent resin)	.15	1.4	.9	43.3	52.8	133.9	.0063	1.5	Table 2	
		2.1	...	36.0	95.5	274	.0130	4.0	Table 4 (0.022)	3/4
		1.2	...	44.0	121.0	324	.0117	3.5	(.022)	3/8
		1.8	...	52.0	155.0	358	.0106	3.7	(.044)	3/8
		2.1	...	60.0	173.0	425	.0113	4.5	(.066)	3/8
Pulpboard (48.3 percent resin)	0.180	1.0	1.1	32.6	...	223.0	0.0104	1.7	Table 5 (0.010)	3/8
		1.5	1.6	25.7	...	175.0	.0111	1.6	(.021)	3/8
		1.7	1.4	30.5	...	233.0	.0104	1.4	(.032)	3/8
		2.3	1.2	29.1	...	217.0	.0112	1.3	(.042)	3/8
		4.6	1.4	31.4	...	216.0	.0109	1.5	(.051)	3/8
		6.0	2.3	28.4	...	205.0	.0122	1.7	(.064)	3/8
		5.3	1.5	31.0	...	188.0	.0101	1.7	(.071)	3/8
		7.1	1.3	30.3	...	204.0	.0100	1.8	(.083)	3/8
		6.2	1.1	30.6	...	278.0	.0101	1.6	(.095)	3/8
		5.6	1.2	27.4	...	220.0	.0114	2.1	(.102)	3/8
Pulpboard (0 percent resin)	.098	.2	...	4.0	...	15.9	.0110	.06	Table 5 ...	3/8
(8.5 percent resin)	.103	.5	...	13.2	...	42.4	.0080	.19	...	3/8
(17.3 percent resin)	.118	.7	...	12.8	...	61.6	.0100	.44	(0.051)	3/8
(27.8 percent resin)	.131	1.4	...	13.6	...	81.0	.0112	.73		3/8
(43.7 percent resin)	.164	7.3	1.3	25.1	...	138.0	.0098	1.70		3/8
(48.3 percent resin)	.178	9.9	1.7	25.2	...	149.0	.0101	2.20		3/8
(57.2 percent resin)	.216	17.0	3.8	39.9	...	247.0	.0090	3.20		3/8
(70.0 percent resin)	.308	42.3	7.0	66.6	...	535.0	.0157	7.25		3/8
Sponge rubber (special)	.125	1.0	...	.8	...	...	...	.31	Table 2	7/16
		2.4	...	2.4	...	...	...	.59	(0.008)	7/8
		2.8	...	2.2	...	...	...	.50		1-1/4
		1.5	...	1.3	...	...	...	.40		1-5/8
		1.2	...	1.2	...	...	...	.25		2
Spruce plywood	.41	50.0	35.0	1,975.0	3,100.0	4,670.0	.0064	...	Table 2	3/16
		51.7	34.4	1,280.0	3,010.0	4,760.0	.0049	...	(0.020)	3/8
		49.6	36.9	967.0	3,700.0	4,160.0	.0049	...		3/4

Sheet 3 of 3

[1] Use for all end-grain constructions.

[2] 1/2-inch gage length.

[3] 1-inch gage length.

[4] From Forest Products Laboratory Report No. 1528.

[5] From Forest Products Laboratory Report No. 1509; used for all calcium alginate.

[6] Use value for all cellular cellulose acetate.

[7] 2-inch gage length.

[8] Use value for all cellular hard rubber.

[9] From Forest Products Laboratory Report No. 1509.

Z M 72689 F

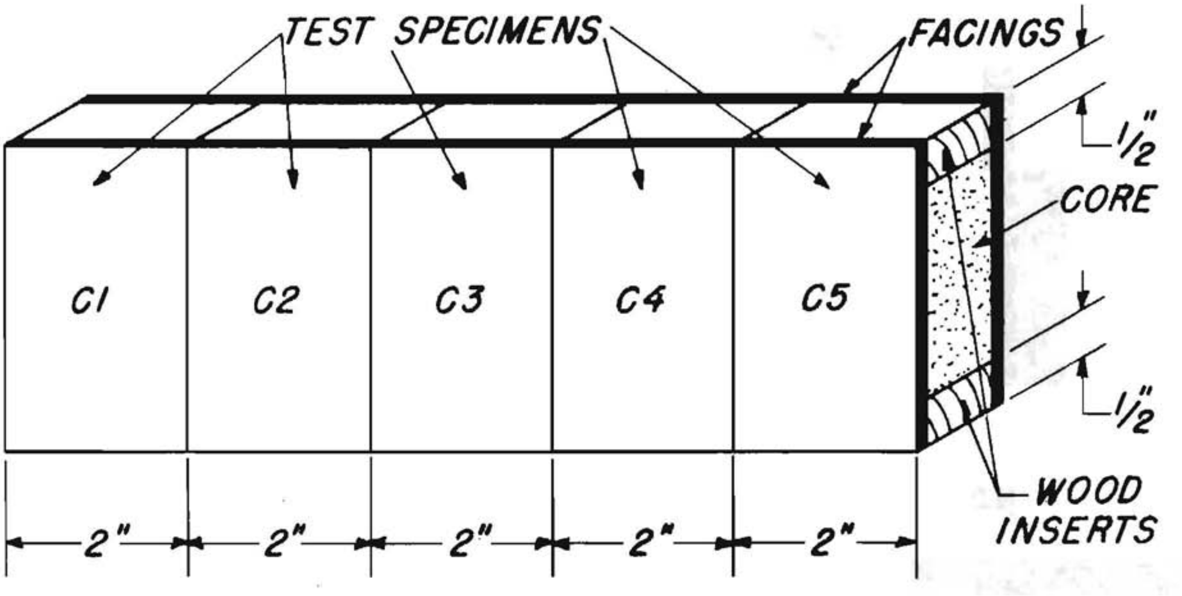

Figure 1.--Sandwich plate, compression-edgewise specimens with wood inserts at the bearing ends.

ZM 72644 F

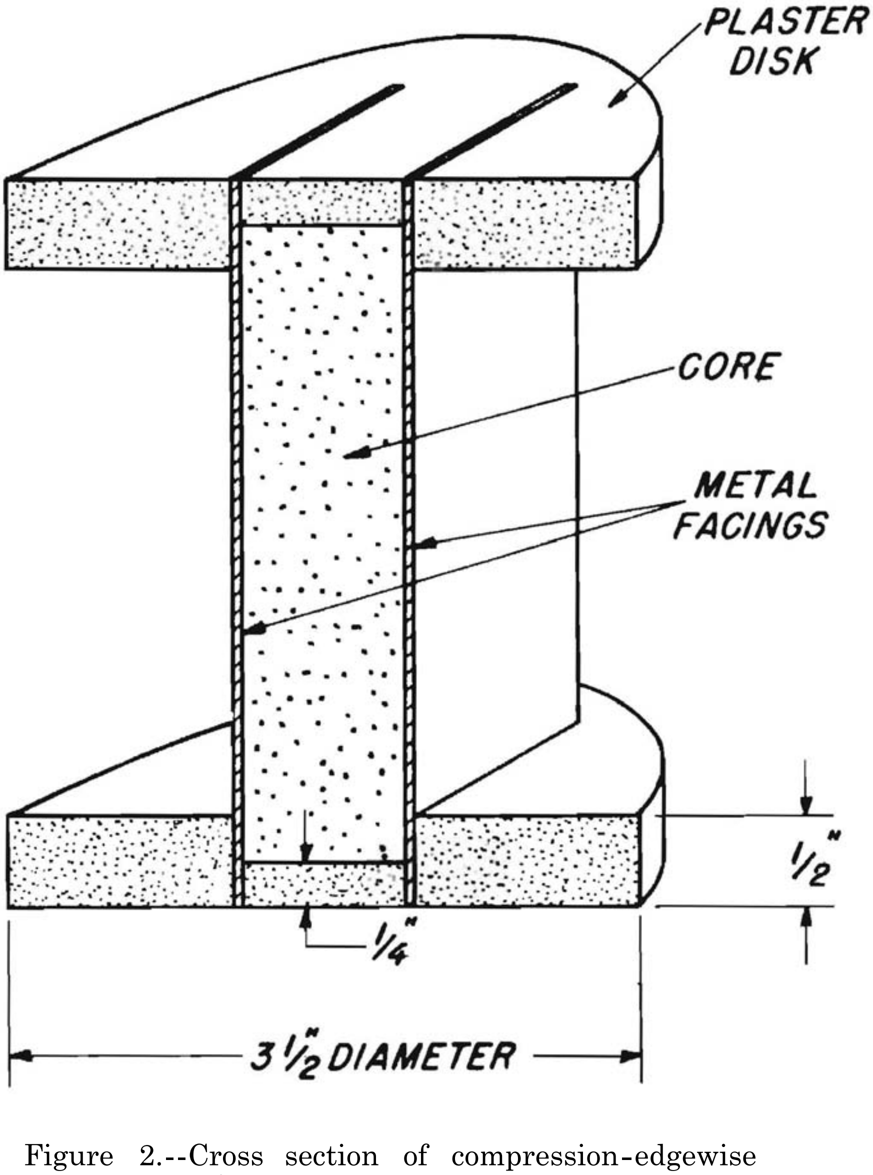

Figure 2.--Cross section of compression-edgewise specimen of sandwich plate with plaster disks at the bearing ends.

ZM 72645 F

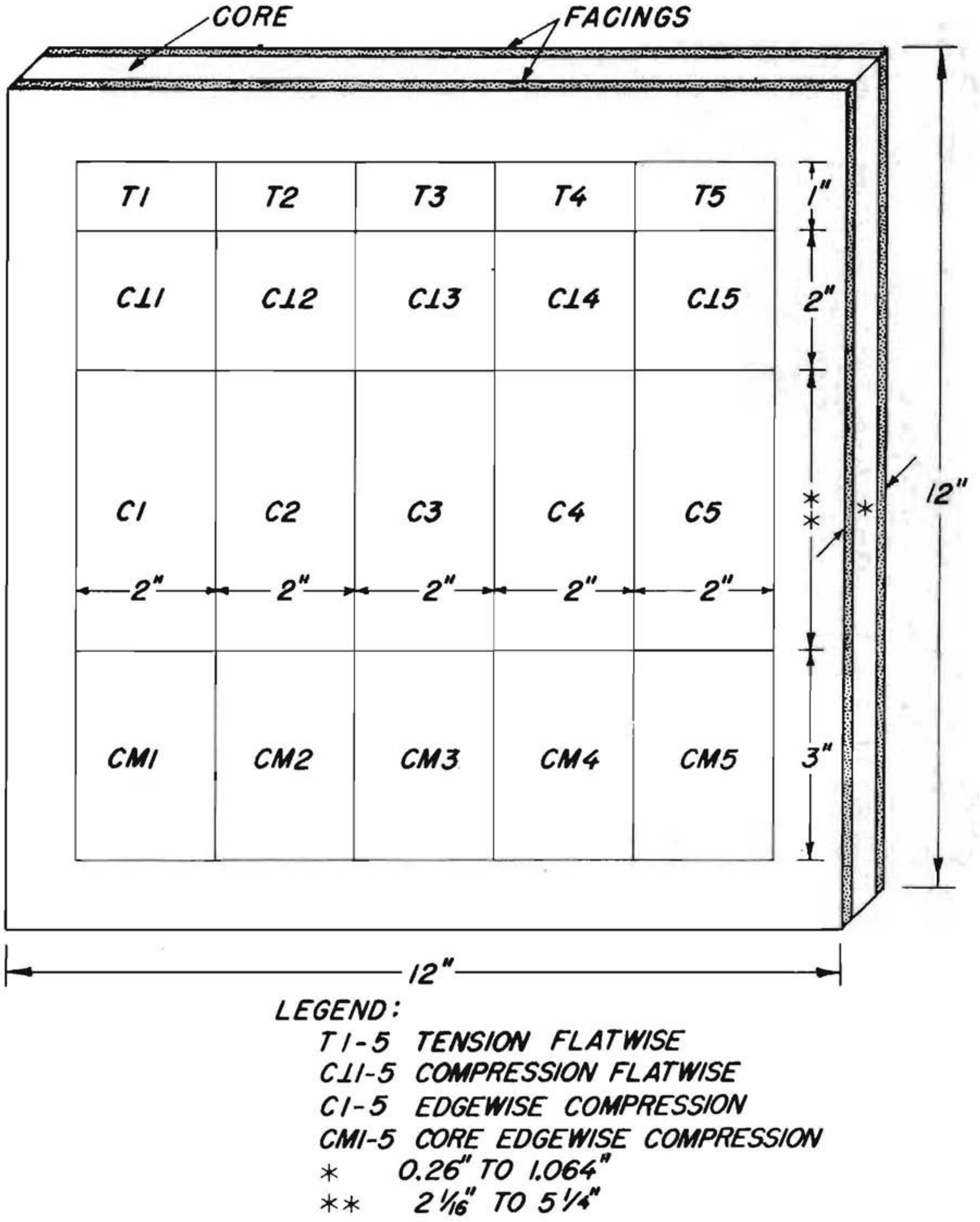

Figure 3.--Layout diagram for edgewise compression tests of flat sandwich plates.

ZM 72646 F

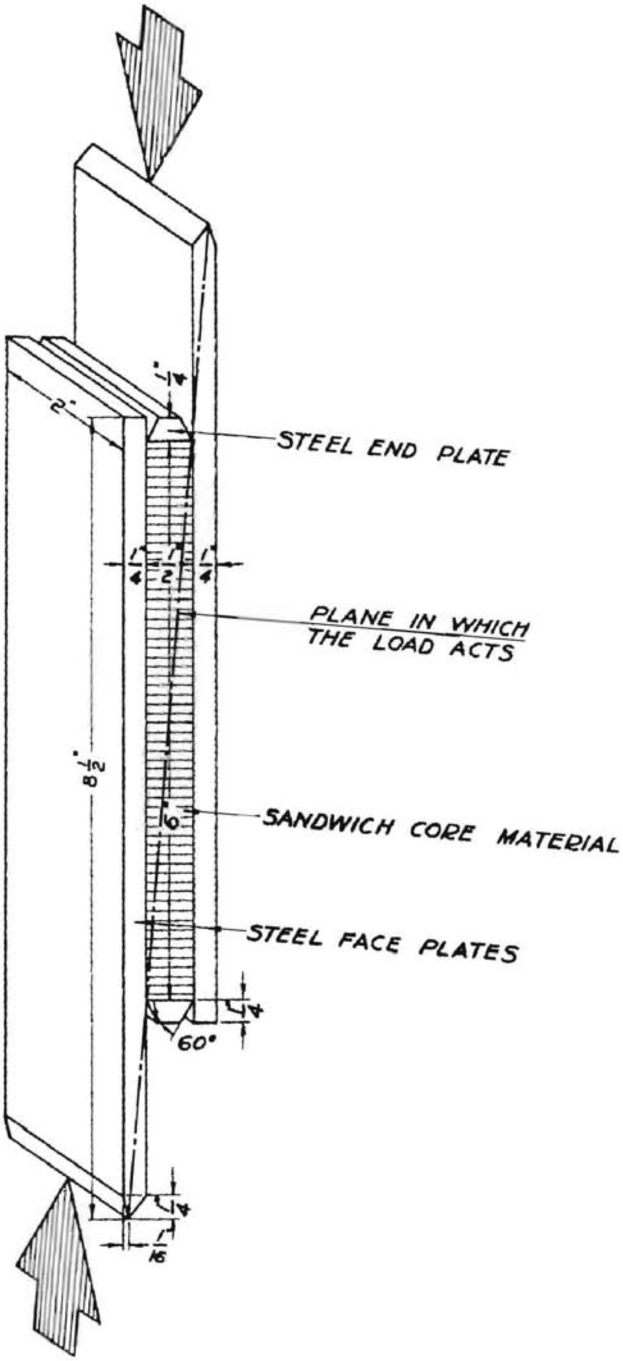

Figure 4.--Frame-shear test for sandwich core material.

Z M 68071 F

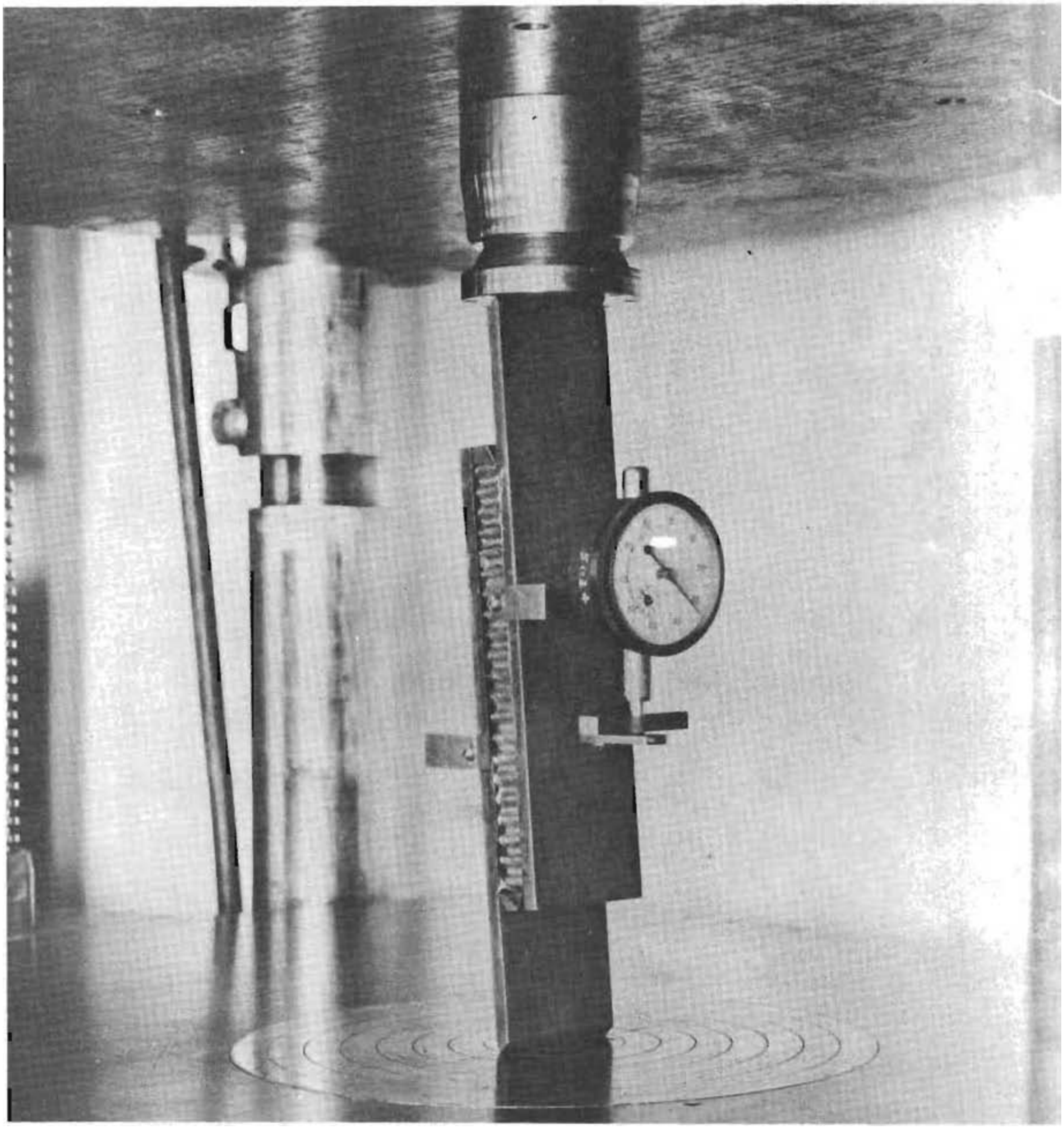

Figure 5.--Apparatus for frame-shear test showing steel plates, honeycomb core, and dial arrangement for measuring deformations between plates.

ZM 73512 F

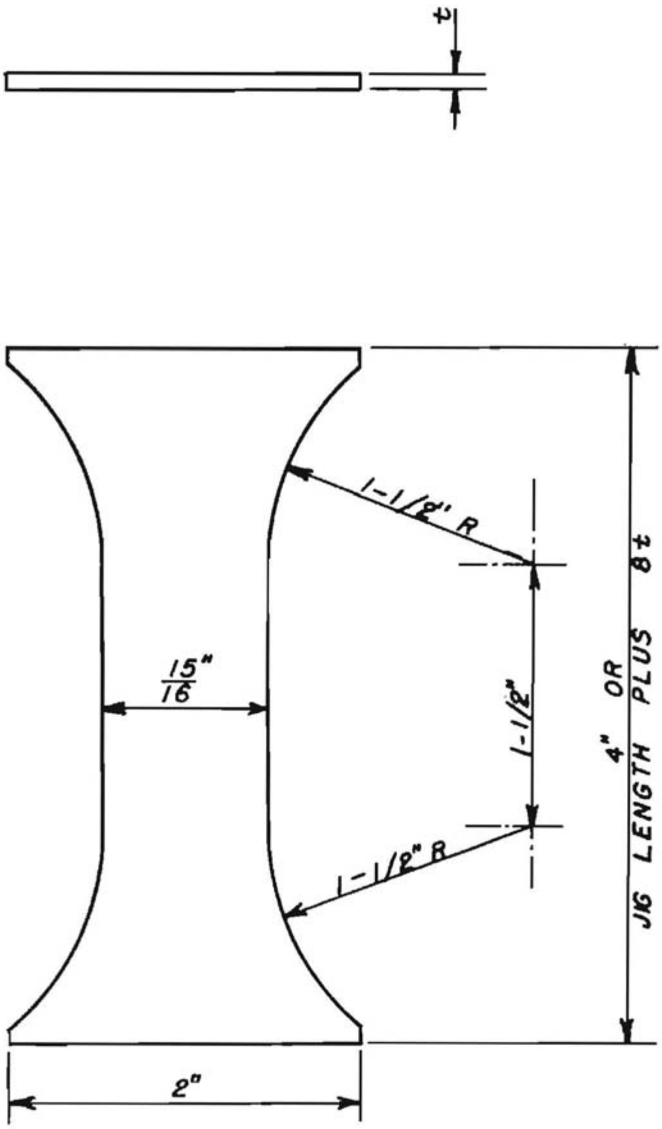

Figure 6.--Compressionspecimen for edgewise tests of thin single-sheet material.

ZM 71321 F

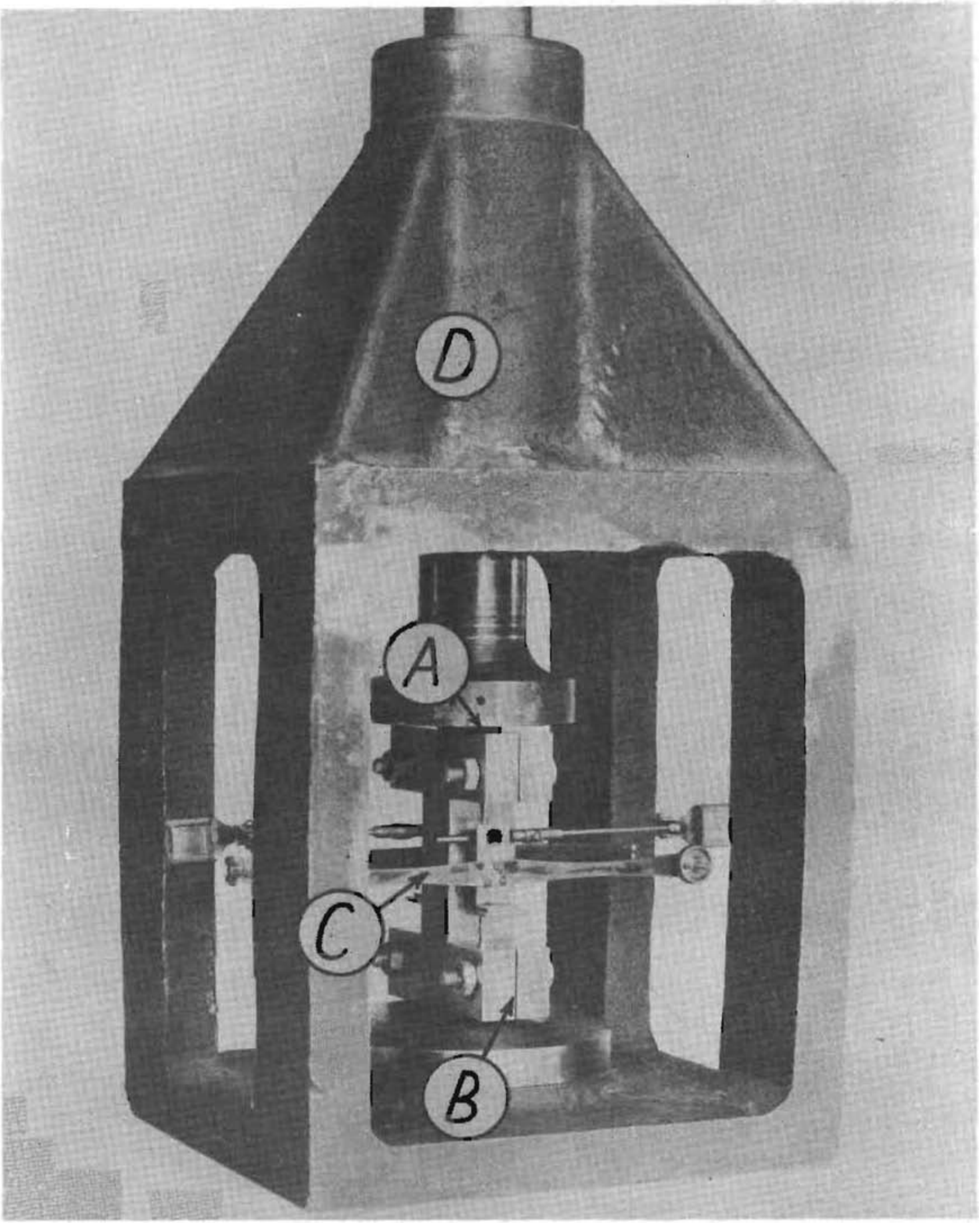

Figure 7.--Compression-edgewise test of thin single-sheet material with continuous support: A, Specimen; B, steel plates; C, Marten's mirror strain gage; D, supporting jig.

ZM 71923 F

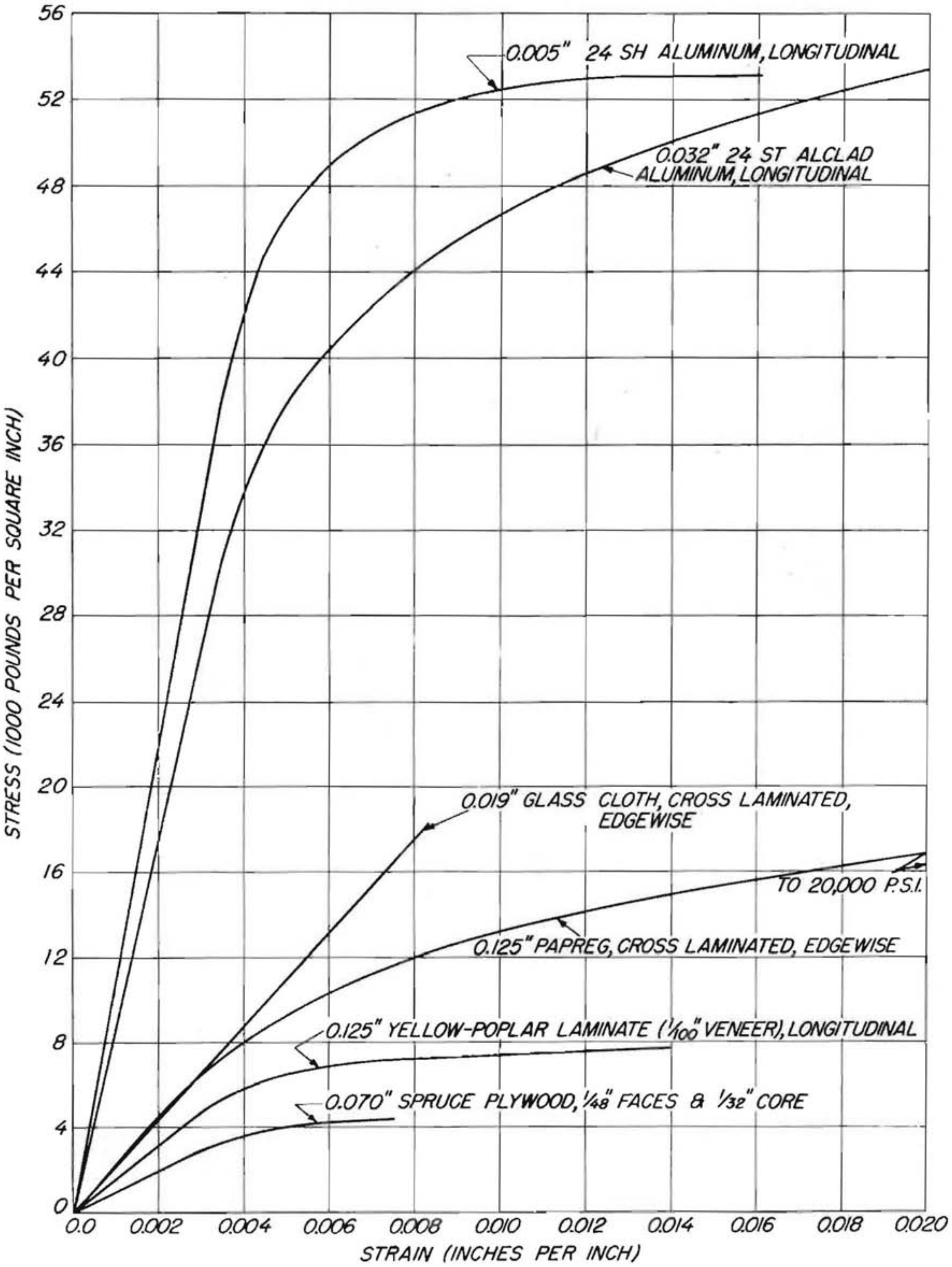

Figure 8.--Typical stress-strain curves of facing materials in edgewise compression.

Z M 72647 F

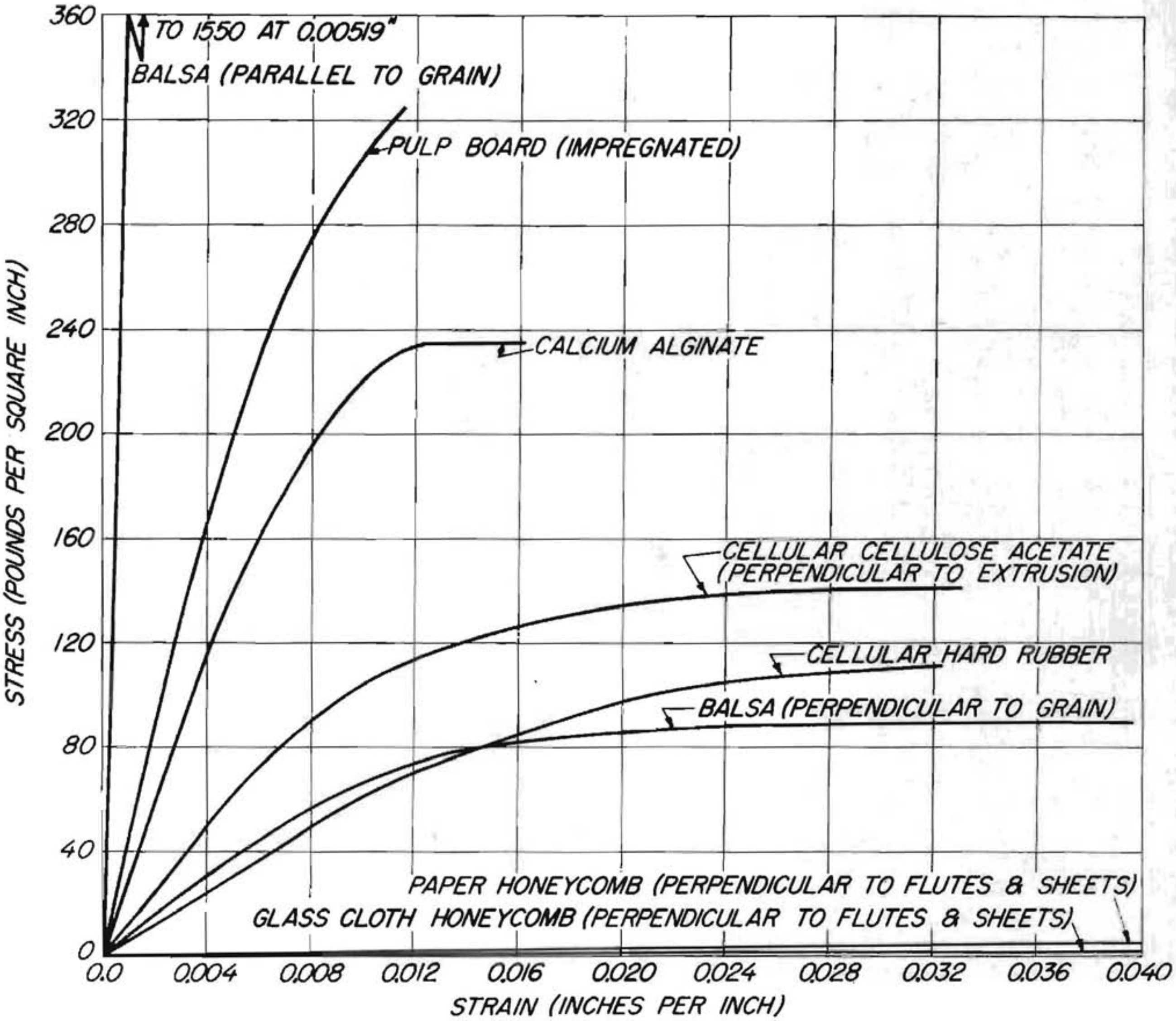

Figure 9.--Typical stress-strain curves of core materials in edgewise compression.

ZM 72648 F