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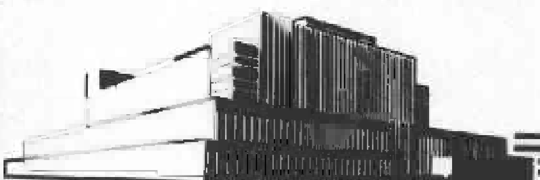

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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

In Cooperation with the University of Wisconsin

EFFECT OF DEFECTS ON STRENGTH OF AIRCRAFT TYPE SANDWICH PANELS[1,2]

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Summary

This study was conducted to determine the effect of several specific types of defects on the strength of properties of a limited number of typical aircraft sandwich constructions.

Poor bonds in sandwich constructions of aluminum facings on balsa core and of glass-cloth facings on balsa core reduced the flatwise tensile strength considerably more than they reduced the bending and edgewise compressive strengths. Unbonded areas from 1 to 3 inches in diameter caused substantial reductions in the edgewise compressive strength of specimens 6 inches wide.

Wrinkles in the glass-cloth facings of specimens having balsa or glass-cloth honeycomb cores reduced the bending, edgewise compressive, and longitudinal tensile values by amounts in proportion to the depth of the wrinkles. No appreciable effect was produced on the bending and longitudinal tensile strengths by increasing the number of plies in the facings of similar specimens gradually or abruptly from 5 to 10. Butt joints in glass-cloth facings resulted in no effect on the edgewise compressive strength, but reductions were evident on the bending and longitudinal

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[2]This report covers the second part of a continuing study, the first part of which was presented in Forest Products Laboratory Report No. 1809 of the same title.

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

tensile strengths. A fold in the glass-cloth facing caused considerable reductions in bending, edgewise compression, and longitudinal tension.

Introduction

The purpose of this study was to make a more thorough investigation of the effect of defects on the strength properties of typical sandwich panels of the aircraft type. A preliminary study was previously initiated by the ANC-23 Subcommittee on Sandwich Construction at the Forest Products Laboratory, and the results were published in Forest Products Laboratory Report No. 1809, dated September 1949. The effect of the defects studied in Report No. 1809 was based mainly on the results of edgewise compression tests. That study was expanded, therefore, to include the effects of specific defects on the longitudinal tensile and bending strengths as well as on the edgewise compressive strength.

Defects and Panel Constructions

Six types of defects were investigated and were incorporated in both facings of the sandwich constructions. The defects are listed below.

1. Poor bonds.--Sandwich panels incorporating this defect were made by producing bonds of low strength between the facings and the core. The amount of work done on this phase was limited because of the inability to obtain consistent reduced flatwise tensile strengths between different test panels or even within the same panel.

2. Unbonded areas.--Unbonded areas between the facings and core, 1, 2, and 3 inches in diameter, were included in the center of 6- by 12-inch sandwich panels for edgewise-compression tests.

3. Wrinkles in facing.--The term "wrinkles" applies to grooves or narrow depressions produced in the glass-cloth facings during fabrication. The size of wrinkle was determined by measuring the depth of the grooves compared with the surrounding surface, and the depths tested were approximately 0.005, 0.010, 0.020, and 0.030 inch.

4. Variation in facing thickness.--Test specimens including this defect were made with abrupt and gradual changes in thickness. Only one method of variation was incorporated in a test specimen, and the details of construction are shown in figure 1.

5. Butt joints in glass-cloth facings.--A butt joint consisted of two pieces of glass cloth placed so that the edges met but did not overlap. Each ply of the glass-cloth facings contained a butt joint. The joint in one ply was 1 inch from the joints of the adjacent plies, and the

joints of every other ply were directly over one another, as shown in figure 1.

6. Folds in glass-cloth facings.--Folds were formed in facings by doubling back the entire facing as a unit. The width of the folds was made as small as possible and ranged from 1/8 to 1/4 inch.

Sandwich Constructions

Three sandwich constructions were used for testing the defects and are given below.

1. Ten-ply glass-cloth facings (112 cloth, finish 114) laminated with the liquid component of adhesive 34[4] were bonded to an end-grain balsa core 0.500 inch thick. The density of the balsa was within the range of 7 to 9 pounds per cubic foot.

2. Aluminum facings (24ST) 0.020 inch thick were bonded to an end-grain balsa core 0.500 inch thick with primary adhesive 25[4] and secondary adhesive 29.[4] The density of the balsa core was within the range of 7 to 9 pounds per cubic foot.

3. Ten-ply glass-cloth facings (112 cloth, finish 114) laminated with polyester resin 2[4] were bonded to glass-cloth honeycomb core 47[4] that was 0.500 inch thick. The core had hexagonal cells 1/4 inch in diameter and fell within the range of 7.5 to 8.5 pounds per cubic foot.

The first sandwich construction was used for all defects, the second for defects 1 and 2, and the third for defects 3 through 6. Control panels were made of all constructions.

Test Methods

Four tests were used to evaluate the effect of the defects in sandwich construction, flatwise and longitudinal tension, edgewise compression, and static bending. Details regarding the test methods are given in Forest Products Laboratory Report No. 1556, "Methods for Conducting Mechanical Tests of Sandwich Construction at Normal Temperatures" (revised February 1950), except for variations mentioned below.

Twenty flatwise tension specimens were made on sandwich panels containing poor bonds to determine the relative quality of the bond as compared to the control sandwich panels.

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[4]See Appendix I.

Longitudinal-tension tests were used for defects 3 to 6, inclusive. The length of the tensile specimen used in these tests was 16 inches, and the thickness was determined by the construction of the facings, which was 10 plies of 112 glass cloth, or approximately 0.030 inch. The full width sections at the ends were 1-1/2 inches wide and 2-7/8 inches long, and the minimum width section at the middle was 0.8 inch wide and 2-1/2 inches long. The maximum and minimum width sections were connected by circular arcs of 20-inch radius tangent to the minimum section. This type of specimen was selected because it has a long, tapered section that results in a uniform stress distribution at the test section.

The specimens were cut and shaped as a sandwich panel, and then the facings were cut from the core by a band saw. A small amount of core material was left on the facings to make sure no injury was caused to the facings. Ten longitudinal tensile specimens were made for each condition. The specimens were tested in a mechanical testing machine equipped with Templin tension grips, and the load was applied at a head speed of approximately 0.05 inch per minute.

Two sizes of edgewise-compression specimens were tested; one was 2 inches by 3 inches, and the other was 6 inches by 12 inches with the direction of loading, with each, parallel to the longer dimension. For the 2- by 3-inch specimens, the ends were supported with clamps, but the ends of the 6- by 12-inch specimens were supported with slotted round bars and the sides (parallel to direction of load) with angle iron. Details of the test set-up are shown in figures 2 and 3. The 2- by 3-inch specimen was used for defects 1, 3, 5, and 6, and the 6- by 12-inch specimen for defect 2. Ten specimens were tested for each condition.

The static bending specimen was about 1/2 inch thick, 1 inch wide, and 16 inches long. The distance between supports was 15 inches, and the load was applied by two loading blocks positioned 1-1/2 inches on each side of the center of the specimen, which made a total of three inches between the load points. The load was applied at a head speed of approximately 0.07 inch per minute. Five bending tests were made from the control and defective panels except the panel with defect 2.

The type of tests used to evaluate the defects varied depending upon the characteristics of the defect. The general cutting diagram followed to obtain reasonable distribution of test specimens is shown in figure 4. Usually bending and longitudinal tensile tests were cut from 18- by 18-inch panels, and edgewise compressive and flatwise tensile tests from 12-by 12-inch panels. Calculations for all specimens with glass-cloth facings were based on a facing thickness of 0.030 inch.

Fabrication of Test Panels

The number and size of the test panels varied with the defect, depending on the types of tests that were used for evaluation. Fabrication procedures for the three constructions and the methods used to incorporate the defects in the test panels are described below.

Controls

The facings of the first sandwich construction (glass-cloth facings on balsa core) were 10 plies of 112 glass cloth impregnated with the liquid component of adhesive 34. The liquid adhesive was used as received or thinned slightly with ethyl alcohol. After the individual sheets were impregnated, they were hung up to dry overnight so that the volatile solvents could escape. The resulting resin content was from 45 to 50 percent based on the total weight of the glass cloth and resin. The balsa core was sprayed with thinned liquid of adhesive 34 and then dusted with the thermoplastic powder (the other component of adhesive 34). The facings were cross-laminated at an angle of approximately 90°, assembled with the prepared core on an aluminum mold, and cured in an autoclave at a temperature of 260° F. and a pressure of 70 pounds per square inch for one hour.

The aluminum facings of the aluminum-on-balsa construction were cleaned in a sulphuric acid-sodium dichromate bath, dried, and sprayed with six coats of a priming cement, adhesive 25. After air drying overnight, they were cured in an oven at 325° F. for 30 minutes. The primed surfaces of the facings were then sanded and spread with 10 grams per square foot of phenolic adhesive 29A. The aluminum facings and balsa core then were assembled on a flat aluminum mold and cured in an autoclave at a temperature of 230° F. and a pressure of 75 pounds per square inch for 1 hour.

The third sandwich construction consisted of glass-cloth facings on glass-cloth honeycomb core. The facings were made by impregnating sheets of 112 glass cloth to approximately 50 percent with polyester resin 2 and wet-laminating them into facings on a thin aluminum caul covered with cellophane. Ten plies of glass cloth, cross-laminated at an angle of approximately 90°, constituted a facing. The 0.500-inch-thick core material was roller-coated with the same resin to a spread of 10 grams per square foot of surface. The facings and core were then assembled and bag-molded in an autoclave at a temperature of 250° F. and a pressure of 15 pounds per square inch for one hour.

Defect 1 - Poor Bonds

Glass-cloth facings impregnated with the liquid component of adhesive 34 were poorly bonded to a balsa core by a two-step process, of which the first step consisted of prefabricating nine-ply facings. After the nine-ply facings were cured, one side of each facing was sanded and bonded to the balsa core with a single ply of impregnated cloth. The single ply was impregnated to 43 percent for one panel and 65 percent for another. Use of only one ply of impregnated glass cloth to bond the precured facings to the balsa core reduced the amount of adhesive available and thereby reduced the strength between the facings and core. Other fabricating conditions were the same as used for the control panels.

Poor bonds in the sandwich construction of aluminum facings on balsa core were made by reducing the spread of the secondary adhesive. Glue spreads of 5 and 1 grams per square foot of adhesive 29A were used on the primed aluminum facings to obtain 2 degrees of reduced strength.

Defect 2 - Unbonded Areas

The procedure for producing unbonded areas varied with the sandwich construction used. With the glass-cloth facings laminated to the balsa core with the liquid portion of adhesive 34, the area on the core to be unbonded was covered with tape before the core was sized with the adhesive. When the sandwich panel was ready for assembling, the tape was removed and two pieces of cellophane, cut to the size of the defect, were inserted between the core and each facing. Regardless of the precautions taken, there always appeared to be a certain degree of bond between the surfaces, probably because of the heat and pressure applied. Therefore, after the test panels were fabricated, the unbonded areas were heated by placing a flatiron over them until the facing showed a slight rise. On cooling, the facing would contract to its original position, and defective area was then inspected by tapping. If the unbonded area was not easily detectable by this method, the process was repeated.

With the combination of aluminum facings on balsa core, tape was applied to the area of the facing that was to be unbonded. After spreading the facings with adhesive 29A, the tape was removed, which left a clean surface at the center the size of the defect. The panels were assembled, cured at 230° F., and cooled under pressure. If the unbonded areas were not detectable by tapping, localized heat was applied and then inspected again as mentioned above.

Defect 3 - Wrinkles

The two sandwich constructions employed for this portion of the work had glass-cloth facings. The wrinkles were formed in the facings by the use of copper wires stretched across the molds and cauls under the cellophane. By varying the size of wire, the size of the wrinkle was controlled to depths of approximately 0.005, 0.010, 0.020, and 0.030 inch.

Defect 4 - Variation in Facing Thickness

The abrupt and gradual methods of varying the facing thickness with glass cloth are shown in figure 1. The five short plies of cloth were placed nearest the core, and the plies that extended the full length of the panel formed the outer portion of the facing. Because of the variation in facing thickness, it was necessary to use bag-molding methods so that uniform pressure was applied to all parts of the panel.

Defect 5 - Butt Joints in Glass-Cloth Facings

The same fabrication procedures were applied to making these test panels as were used for the controls of the two glass-cloth-faced sandwich constructions, except that a butt joint was incorporated in each ply. Butt joints of adjacent plies were spaced 1 inch apart and directly over one another on alternate plies, as shown in figure 1.

Defect 6 - Folds in Glass-Cloth Facings

Both sandwich constructions with glass-cloth facings were used for this part. The entire facing was bent back on itself for about 1/8 to 1/4 inch, forming a figure S. By holding the folds down, the facings were assembled with the core and prepared for curing as discussed under "controls."

Results and Discussion

There are many factors that may affect the strength properties of sandwich construction in addition to the defects incorporated, such as uniformity of core thickness, resin content of facings, fabricating equipment, and curing conditions. Care was exercised to minimize the effect of these variables as much as possible, but their effect cannot be eliminated entirely.

Poor Bonds

The results of tests conducted on sandwich panels with poor bonds are summarized in table 1. Although the flatwise tensile strength of the sandwich combinations (glass cloth plus adhesive 34 on balsa) was reduced more than 50 percent (from 1,005 to 484 pounds per square inch), the bending and edgewise compressive strengths were only reduced about 10 percent. As the bond strength between the facings and core decreased, the percentage of core failure of the flatwise tension tests was reduced. Although the bending moment at failure of the poorest bond indicated only a slight reduction from that of the controls, it should be noted that the type of failure changed from a compression failure in the facing to horizontal shear failure at the bond between the facing and core. This was not true for the edgewise compression tests, where the type of failure remained constant.

The results obtained from tests on the aluminum-on-balsa sandwich combination were somewhat similar to those discussed for the construction above. The average tensile strength of the poorest bonds was considerably weaker (110 pounds per square inch), and again a progressive reduction in core failure was obtained. The bending moment was not materially reduced by a tensile reduction from 901 to 721 pounds per square inch, but a reduction in tensile strength of approximately 90 percent (to 110 pounds per square inch) resulted in a decrease of 40 percent in the bending moment. The latter was also accompanied by a change in the type of failure, as was noted in the sandwich construction of glass cloth -- adhesive 34 on balsa. The edgewise compressive strength was not materially affected by the poor bonds between the core and facings.

The work done on this defect was limited because of the difficulty of fabricating test panels with uniformly poor bonds. Experimental panels were made to determine the spread of adhesive to be used, but considerable variation was obtained between the experimental and actual test panels. There was also considerable variation within the test panel itself, as seen by the maximum and minimum values of tensile strength.

Unbonded Areas

The results of the edgewise compression tests made on sandwich panels with unbonded areas are summarized in table 2. As the size of the unbonded area increased, the edgewise compressive strength decreased. With the sandwich construction of glass cloth -- adhesive 34 on balsa, the compressive strength decreased proportionately as the diameter of the unbonded area of the compression specimen increased (fig. 5). If the line is extended until it crosses the horizontal axis (or zero strength), the indicated diameter of the unbonded area is close to 6 inches (or the width of the specimen).

With the other sandwich construction (aluminum facings on balsa core) the compressive strength decreased as the unbonded area increased, but not in a straight-line relation as with the glass-cloth-faced sandwich construction.

Wrinkles in Facing

The effect of wrinkles in glass-cloth facings on the strength properties of sandwich construction is summarized in table 3. Wrinkles caused considerable reduction in all the strength properties tested. In general, as the depth of the wrinkle increased, the strength properties tested decreased. When the depth of wrinkles incorporated in the facings was practically equal to the facing thickness, reductions of 65 percent resulted in bending, 62 percent in edgewise compression, and 46 to 62 percent in longitudinal tension. Wrinkles of 0.005-inch depth caused reductions that were significant, and the failures usually occurred at the wrinkle.

Variation in Facing Thickness

Increasing the thickness of glass-cloth facings of sandwich construction gradually or abruptly had no marked effect on the bending strength, as shown in table 4. Comparisons were made between specimens having these variations and controls with facings of five plies of 112 glass cloth. The type of bending failure obtained in the specimens with facing variations was also quite similar to those obtained with the control specimens.

Gradual increases in facing thickness produced small increases in the longitudinal tensile strength. Abrupt increases in facing thickness with the sandwich construction of glass cloth -- adhesive 34 on balsa produced a decrease in longitudinal tensile strength from 38,060 to 31,100 pounds per square inch, but on the other sandwich construction of glass cloth-resin 2 on glass-cloth honeycomb core abrupt increases in facing thickness resulted in an increase from 33,320 to 37,900 pounds per square inch. In the construction mentioned first, the failures occurred where the thickness of the facings changed. It is probable that the abrupt change in facing thickness may cause a concentration of stresses near the change point and cause lower strength values.

Butt Joints in Glass-Cloth Facings

The results pertaining to butt joints in the individual plies of glass-cloth facings of sandwich construction are given in table 5. Two constructions were used, and the results indicated similar trends. No significant effect on the edgewise compressive strength resulted from staggered butt joints in the plies of the facings, but the longitudinal tensile strength was reduced from 17 to 33 percent. A 20 percent reduction in the bending strength was found with the sandwich construction of glass cloth -- adhesive 34 on balsa, but no effect was indicated with the construction of glass cloth -- resin 2 on glass-cloth honeycomb core.

Folds in Glass-Cloth Facings

A summary of results on sandwich panels containing folds in the glass-cloth facings is given in table 5. All the strength properties tested were lowered by this defect. The reductions in bending strength varied from 35 to 65 percent, in edgewise compressive strength from 14 to 42 percent, and in longitudinal tensile strength from 62 to 85 percent. All the small reductions apply to the sandwich construction of glass cloth -- adhesive 34 on balsa core. It is probable that the reductions for this construction were smaller because the greater fabricating pressure made the folds less serious in their effect.

Conclusions

The following conclusions apply to the results of tests reported, based on the limited number of specimens. The sandwich constructions were typical of those being used in the aircraft industry, but do not include all combinations or techniques used.

Flatwise tensile strength was reduced by poor bonds more than were the bending and edgewise compressive strengths. Poor bonds of uniform quality were found very difficult to fabricate.

Substantial reductions in the edgewise compressive strength of 6- by 12-inch sandwich test panels resulted when centrally located unbonded areas from 1 to 3 inches in diameter were incorporated between the facings and core.

As the depth of the wrinkles in the glass-cloth facings increased, the strength of the sandwich construction in bending, edgewise compression, and longitudinal tension decreased.

No appreciable effect was produced on the bending and longitudinal tensile strengths when the number of plies of glass cloth in the facings of the sandwich construction were increased gradually or abruptly.

No effect on the edgewise compressive strength resulted from butt joints in the glass-cloth facings, but bending and longitudinal tensile strengths were reduced.

All the strength properties tested, bending, edgewise compression, and longitudinal tension, were substantially lowered by a fold in the glass-cloth facings of the sandwich construction.

Appendix I

List and General Description of Adhesives and Resins

Adhesive 34 - A high-temperature-setting, two-component resin with a thermosetting liquid and thermoplastic powder.

Adhesive 25 - A high-temperature-setting mixture of thermosetting resin and synthetic rubber.

Adhesive 29 - An intermediate-temperature-setting, acid-catalyzed phenol resin.

Resin 2 - A laminating resin of the polyester (styrene-alkyd) type.

Core 47 - A glass-fabric polyester honeycomb core with 1/4-inch hexagonal cells and a density of approximately 8.4 pounds per cubic foot.

Table 1.--Effect of poor bonds on the strength properties of sandwich construction with 1/2-inch balsa cores

Sandwich construction		Defects	Flatwise tension tests				Bending tests				Edgewise compression tests			
Facings	Adhesive[1]		Tensile strength			Core failure	Bending moment			Number and type[2] of failures	Facing stress			Number and type[3] of failures
			Average[4]	Maximum	Minimum		Average	Maximum	Minimum		Average	Maximum	Minimum	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
			P.s.i.	P.s.i.	P.s.i.	Percent	In.-lb. per in. width	In.-lb. per in. width	In.-lb. per in. width		P.s.i.	P.s.i.	P.s.i.	
Glass-cloth[5] (0.030 inch)	34	Control	1,005	1,320	720	100	509	591	468	1-(b) 3-(c) 1-(e)	33,190	36,400	28,300	10-(b)
Glass-cloth[5] (0.030 inch)	34	Poor bond	722	1,000	390	19	513	600	423	3-(c) 2-(e)	29,900	33,600	26,400	10-(b)
Glass-cloth[5] (0.030 inch)	34	Poor bond	484	710	320	11.5	470	491	453	5-(e)	29,200	32,600	24,800	10-(b)
Aluminum (0.020 inch)	25 + 29	Control	901	1,280	480	66.2	516	540	483	1-(a) 4-(b)	47,700	48,900	45,900	10-(a)
Aluminum (0.020 inch)	25 + 29	Poor bond	721	1,110	330	8.5	490	516	459	1-(a) 4-(b)	47,600	50,400	44,900	2-(a) 3-(b) 5-(c)
Aluminum (0.020 inch)	25 + 29	Poor bond	110	180	20	0.0	307	372	174	5-(e)	47,000	51,100	39,400	10-(c)

[1]See appendix for description of adhesives.

[2]Types of failure for bending tests are (a) offset failure, shear in core, (b) facing wrinkle, failure at bond, (c) failure of facing in compression, and (e) horizontal shear, failure at bond.

[3]Types of failure for edgewise compression test are (a) offset failure, shear in core, (b) failure at bearing end, and (c) facing wrinkle, failure at bond.

[4]Average of 20 specimens.

[5]Ten plies of 112 glass cloth, finish 114, used for facings. Calculations made on basis of facing thickness of 0.030 inch.

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Table 2.--Effect of unbonded areas on the strength properties of sandwich constructions with 1/2-inch balsa cores

Sandwich construction		Diameter of unbonded area	Edgewise compression test			
Facings	Adhesive[1]		Average	Maximum	Minimum	Number and type[2] of failures
(1)	(2)	(3)	(4)	(5)	(6)	(7)
		Inches	P.s.i.	P.s.i.	P.s.i.	
Glass-cloth[3] (0.030 inch)	34	Control	21,620	23,430	18,540	5-(b)
Glass-cloth[3] (0.030 inch)	34	1	18,000	20,000	16,320	5-(c)
Glass-cloth[3] (0.030 inch)	34	2	12,490	12,980	11,820	5-(c)
Glass-cloth[3] (0.030 inch)	34	3	10,510	10,850	10,000	5-(c)
Aluminum (0.020 inch)	25 + 29	Control	52,800	56,900	49,900	4-(a) 1-(b)
Aluminum (0.020 inch)	25 + 29	1	33,700	35,200	32,200	5-(c)
Aluminum (0.020 inch)	25 + 29	2	24,600	29,000	20,800	5-(c)
Aluminum (0.020 inch)	25 + 29	3	20,200	23,000	16,200	5-(c)

[1] See appendix for description of adhesives.

[2] Types of failures for edgewise compression tests are (a) offset failure, shear in core, (b) failure at bearing end, and (c) facing wrinkle, failure at bond.

[3] Ten plies of 112 glass cloth, finish 114, used for facings. Calculations made on basis of facing thickness of 0.030 inch.

Table 3.--Effect of wrinkles in glass-cloth facings on the strength properties of sandwich construction

Sandwich construction				Bending tests				Edgewise compression tests				Longitudinal tension tests			
Facings (10 plies of 112 glass cloth - 0.030 inch)	Core (1/2 inch thick)	Adhesive[1] or resin	Depth of wrinkle	Bending moment: Average	Bending moment: Maximum	Bending moment: Minimum	Number and type[2] of failures	Facing stress: Average	Facing stress: Maximum	Facing stress: Minimum	Number and type[3] of failures	Tensile strength: Average	Tensile strength: Maximum	Tensile strength: Minimum	Number and type[4] of failures
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
			Inch	In.-lb. per in. width	In.-lb. per in. width	In.-lb. per in. width		P.s.i.	P.s.i.	P.s.i.		P.s.i.	P.s.i.	P.s.i.	
Glass-cloth	Balsa	34	Control	509	591	468	5-(c)	33,190	36,400	28,300	10-(b)	40,300	42,400	39,600	10-(b)
Glass-cloth	Balsa	34	0.005	463	481	445	2-(c) 3-(d)	29,720	32,100	27,100	10-(b)	29,950	36,800	24,200	7-(a) 3-(b)
Glass-cloth	Balsa	34	.010	391	421	362	4-(c) 1-(d)	25,500	27,430	22,640	1-(b) 9-(d)	24,460	26,600	22,400	10-(a)
Glass-cloth	Balsa	34	.020	241	290	216	1-(c) 4-(d)	16,360	18,300	14,320	10-(d)	18,710	22,400	14,100	10-(a)
Glass-cloth	Balsa	34	.030	175	191	154	5-(c)	12,200	12,640	10,400	10-(d)	15,240	17,900	12,900	10-(a)
Glass-cloth	Glass-cloth honeycomb	2	Control	443	490	423	1-(b) 3-(c) 1-(e)	24,030	25,500	21,900	1-(b) 9-(d)	38,200	41,100	35,900	8-(b)
Glass-cloth	Glass-cloth honeycomb	2	0.005	283	307	250	4-(c) 1-(e)	18,500	21,400	15,180	1-(b) 9-(d)	33,170	35,200	30,400	1-(a) 9-(b)
Glass-cloth	Glass-cloth honeycomb	2	.010	230	276	197	5-(e)	14,020	16,000	8,400	10-(d)	32,720	38,100	29,800	9-(a) 1-(c)
Glass-cloth	Glass-cloth honeycomb	2	.018	197	224	176	5-(e)	10,040	11,800	8,230	10-(d)	22,050	24,600	17,800	10-(a)
Glass-cloth	Glass-cloth honeycomb	2	.026	157	181	131	5-(e)	9,160	10,200	7,680	10-(d)	20,750	24,600	16,900	10-(a)

[1]See appendix for description of adhesive and resin.

[2]Bending failures are (b) facing wrinkle, failure at bond, (c) failure of facing in compression, (d) failure of facing in tension, and (e) horizontal shear, failure at bond.

[3]Edgewise compression failures are (b) failure at bearing end, and (d) failure of facing in compression.

[4]Longitudinal tension failures are (a) in defect of necked-down portion, (b) outside of defect of necked-down portion, and (c) in or near grips

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Table 4.--Effect of variation in facing thickness on the strength properties of sandwich construction

Sandwich construction			Variation of facing thickness[2]	Bending tests				Longitudinal tension tests			
Facings	Core (1/2 inch thick)	Adhesive[1] or resin		Bending moment			Number and type[3] of failures	Tensile strength			Number and type[4] of failures
				Average	Maximum	Minimum		Average	Maximum	Minimum	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
				In.-lb. per in. width	In.-lb. per in. width	In.-lb. per in. width		P.s.i.	P.s.i.	P.s.i.	
Glass-cloth (0.015 in.)	Balsa	34	Control	240	256	210	5-(c)	38,060	42,000	34,200	10-(b)
Glass-cloth (0.015 to 0.030 inch	Balsa	34	Gradual	259	312	224	5-(c)	41,800	44,000	39,600	10-(b)
Glass-cloth (0.015 to 0.030 inch)	Balsa	34	Abrupt	251	270	224	5-(c)	31,100	35,000	26,800	10-(a)
Glass-cloth (0.015 in.)	Glass-cloth honeycomb	2	Control	148	162	134	4-(b) 1-(c)	33,320	36,400	29,600	9-(b) 1-(c)
Glass-cloth (0.015 to 0.030 inch)	Glass-cloth honeycomb	2	Gradual	139	193	104	4-(b) 1-(c)	38,000	40,200	36,200	6-(b)
Glass-cloth (0.015 to 0.030 inch)	Glass-cloth honeycomb	2	Abrupt	147	176	124	5-(b)	37,900	40,600	35,800	9-(b)

[1]See appendix for description of adhesive and resin.

[2]Facing varied from 5 to 10 plies of 112 glass cloth, finish 114, abruptly or gradually over 2-inch span.

[3]Bending failures are (b) facing wrinkle, failure at bond, and (c) failure of facing in compression.

[4]Longitudinal tension failures are (a) in defect of necked-down portion, (b) outside of defect in necked-down portion, and (c) in or near grips.

Table 5.--Effect of butt joints or folds in the facings on the strength properties of sandwich construction

Sandwich construction: Facings (0.030 inch)	Sandwich construction: Core (1/2 inch thick)	Sandwich construction: Adhesive[1] or resin	Defect	Bending tests: Bending moment: Average	Bending tests: Bending moment: Maximum	Bending tests: Bending moment: Minimum	Bending tests: Number and type[2] of failures	Edgewise compression tests: Facing stress: Average	Edgewise compression tests: Facing stress: Maximum	Edgewise compression tests: Facing stress: Minimum	Edgewise compression tests: Number and type[3] of failures	Longitudinal tension tests: Tensile strength: Average	Longitudinal tension tests: Tensile strength: Maximum	Longitudinal tension tests: Tensile strength: Minimum	Longitudinal tension tests: Number and type[4] of failures
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
				In.-lb. per in. width	In.-lb. per in. width	In.-lb. per in. width		P.s.i.	P.s.i.	P.s.i.		P.s.i.	P.s.i.	P.s.i.	
Glass-cloth	Balsa	34	Control	509	591	468	5-(c)	33,190	36,400	28,300	10-(b)	40,300	42,400	39,600	10-(b)
Glass-cloth	Balsa	34	Butt joint	404	425	372	3-(c) 2-(d)	32,380	34,000	30,700	8-(b) 2-(d)	27,100	30,700	25,500	10-(a)
Glass-cloth	Balsa	34	Fold	329	343	306	5-(c) and (d)	28,500	31,400	23,250	8-(b) 2-(d)	15,420	18,100	12,000	10-(a)
Glass-cloth	Glass-cloth honeycomb	2	Control	443	490	423	1-(b) 3-(c) 1-(e)	24,030	25,500	21,900	1-(b) 9-(d)	38,200	41,100	34,900	8-(b)
Glass-cloth	Glass-cloth honeycomb	2	Butt joint	450	491	378	5-(c)	23,810	27,600	20,700	7-(b) 3-(d)	31,600	34,400	28,400	10-(a)
Glass cloth	Glass-cloth honeycomb	2	Fold	153	173	136	1-(b) 4-(d)	13,830	14,880	12,900	10-(b)	5,780	7,110	4,940	10-(a)

[1]See appendix for description of adhesive and resin.

[2]Bending failures are (b) facing wrinkle, failure at bond, (c) failure of facing in compression, (d) failure of facing in tension, and (e) horizontal shear, failure at bond.

[3]Edgewise compression failures are (b) failure at bearing end, and (d) failure of facing in compression.

[4]Longitudinal tension failures are (a) in defect of necked-down portion, and (b) outside of defect of necked-down portion.

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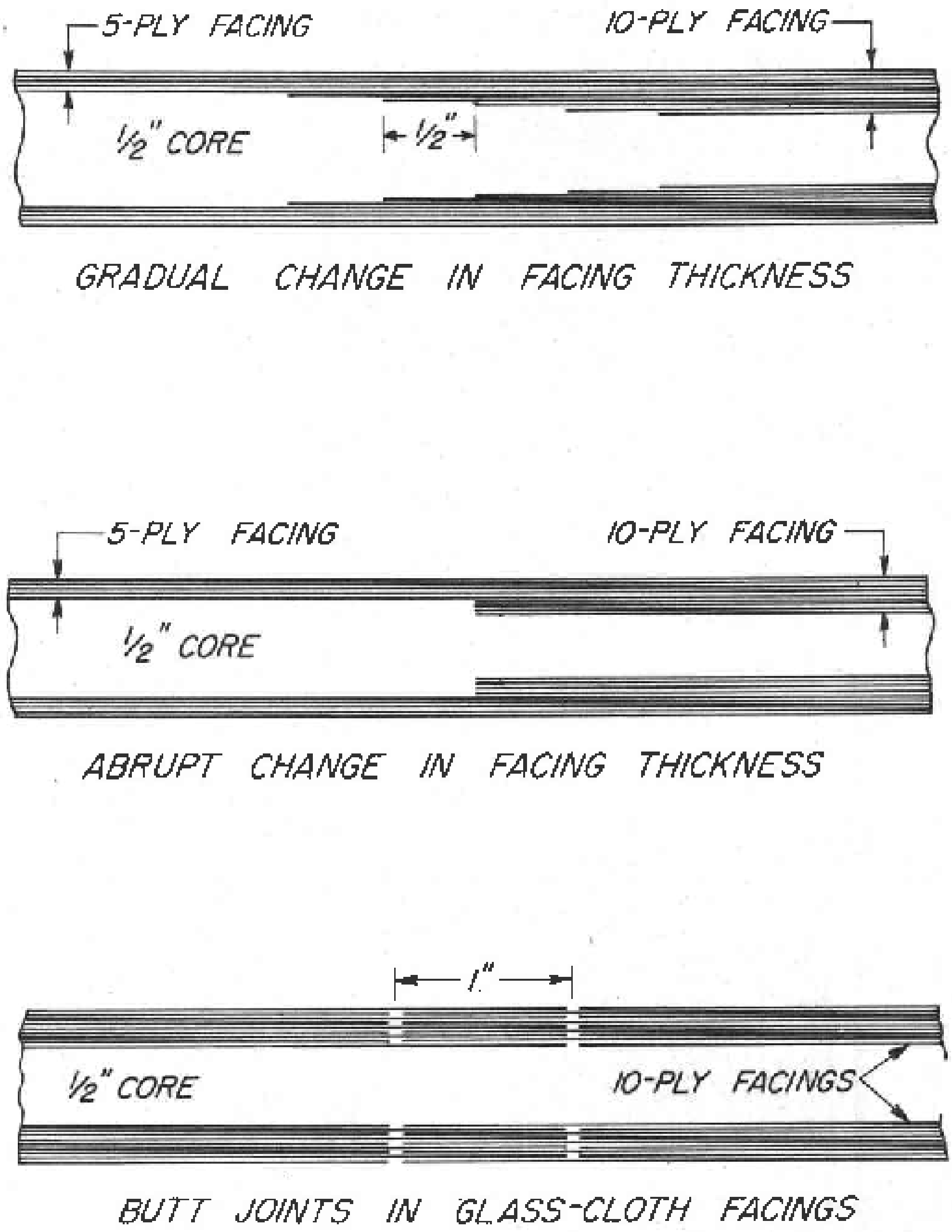

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Figure 1. --Diagrammatic sketches of details of sandwich construction with defect 4, variation in facing thickness, and defect 5, butt joints in glass-cloth facings.

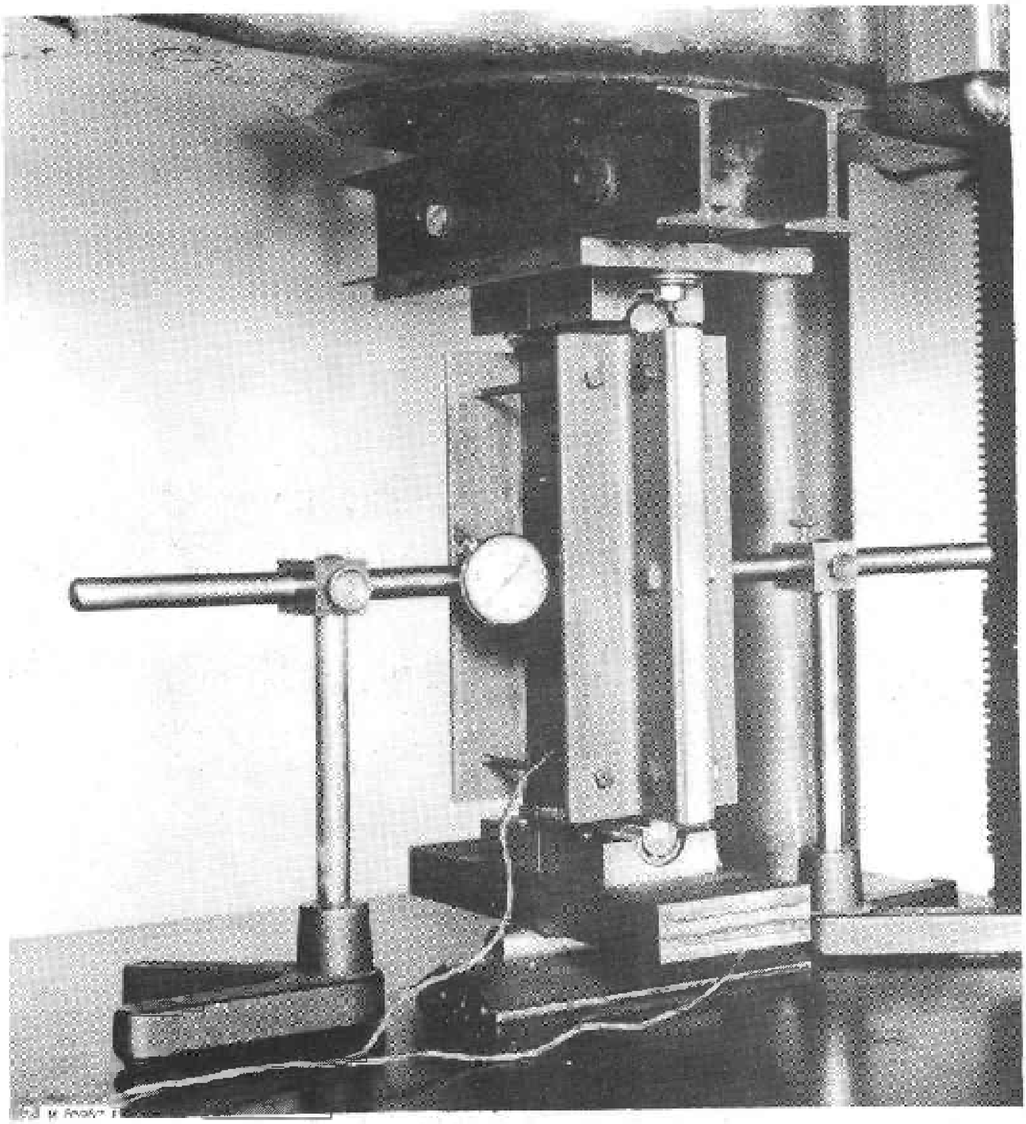

Figure 2. --Complete arrangement for testing 6- by 12-inch edgwise compression specimens.

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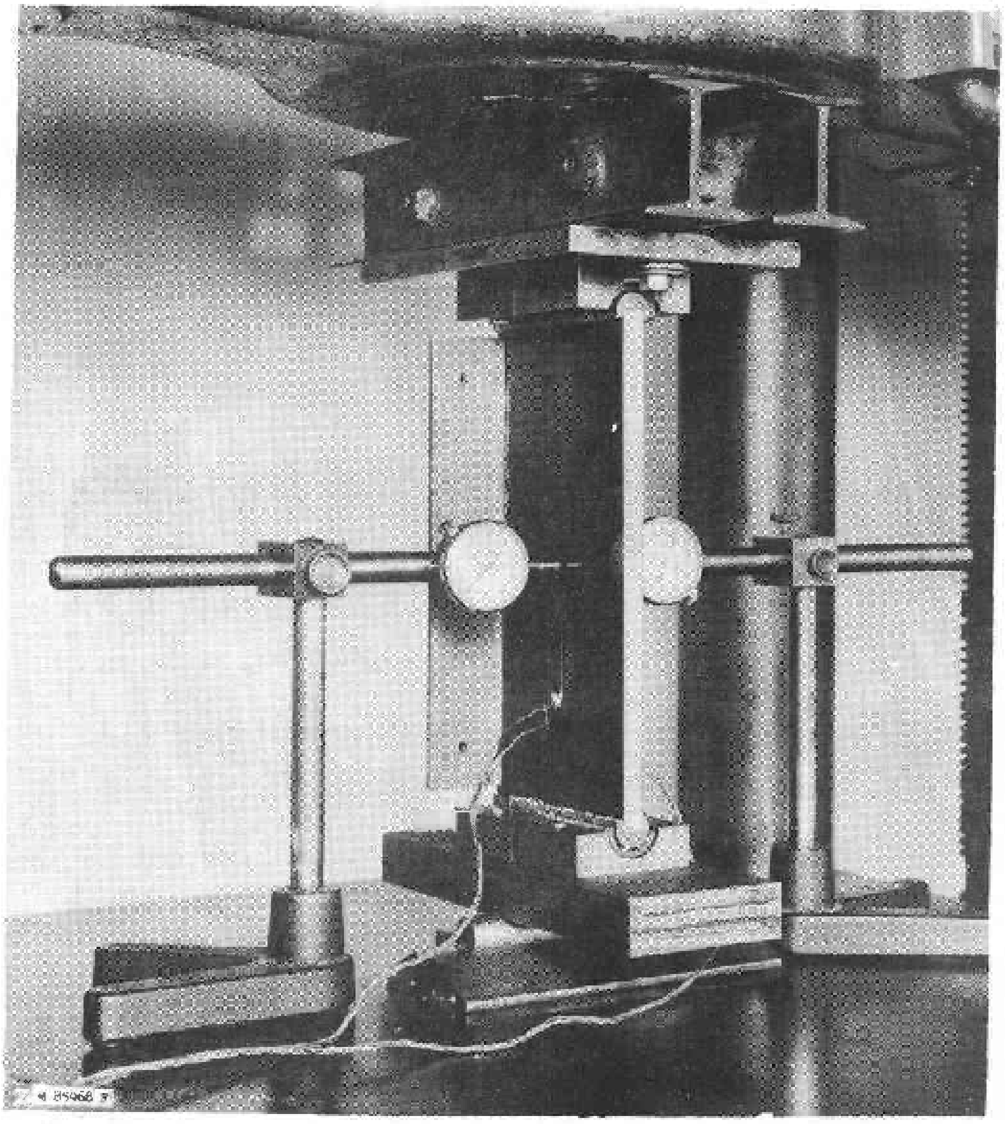

Figure 3. --The 6- by 12-inch edgewise compression test with supports along the length removed to show dial gages and strain gages.

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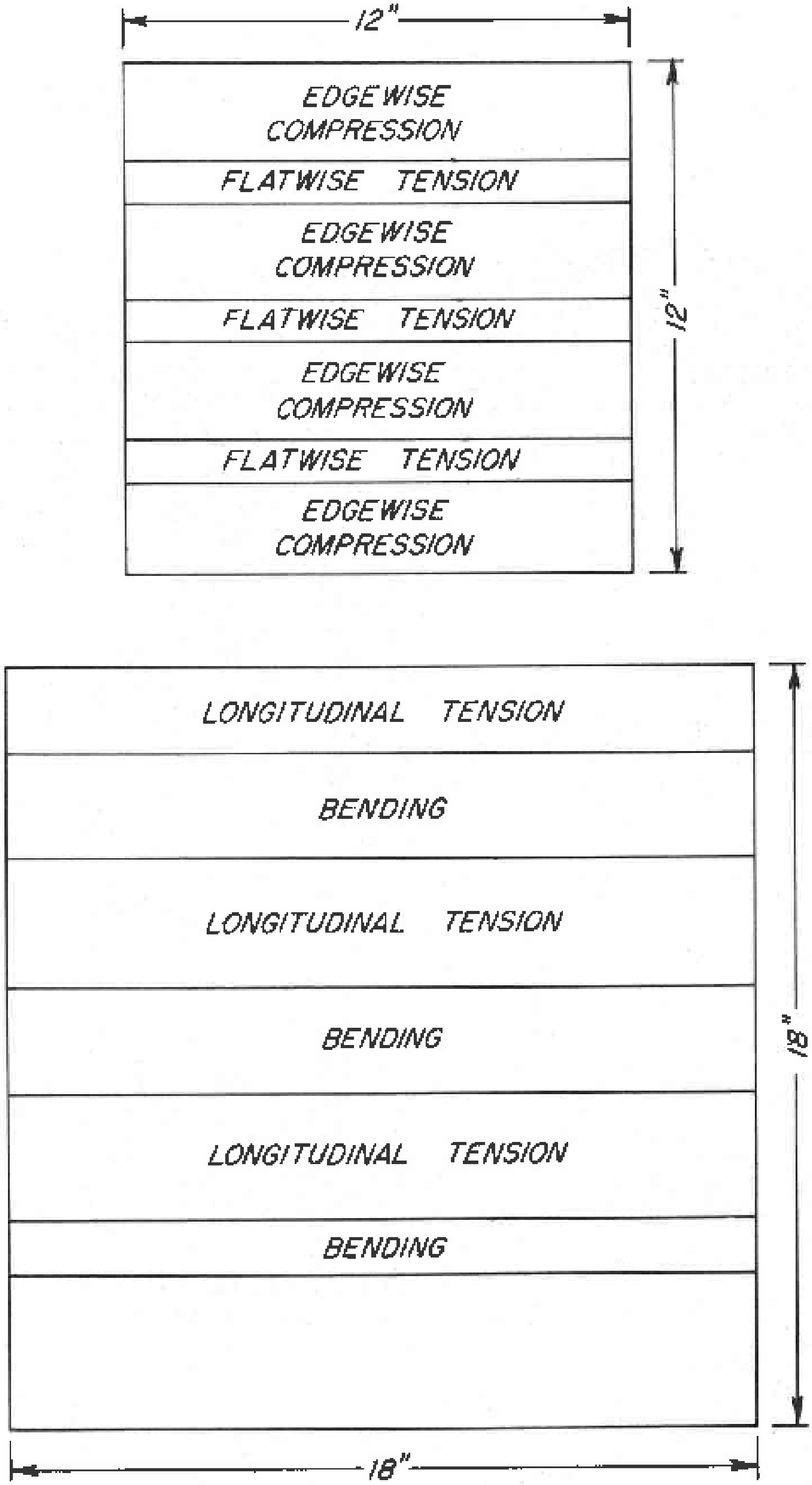

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Figure 4. --General cutting diagram used to obtain distribution of specimens from test panels.

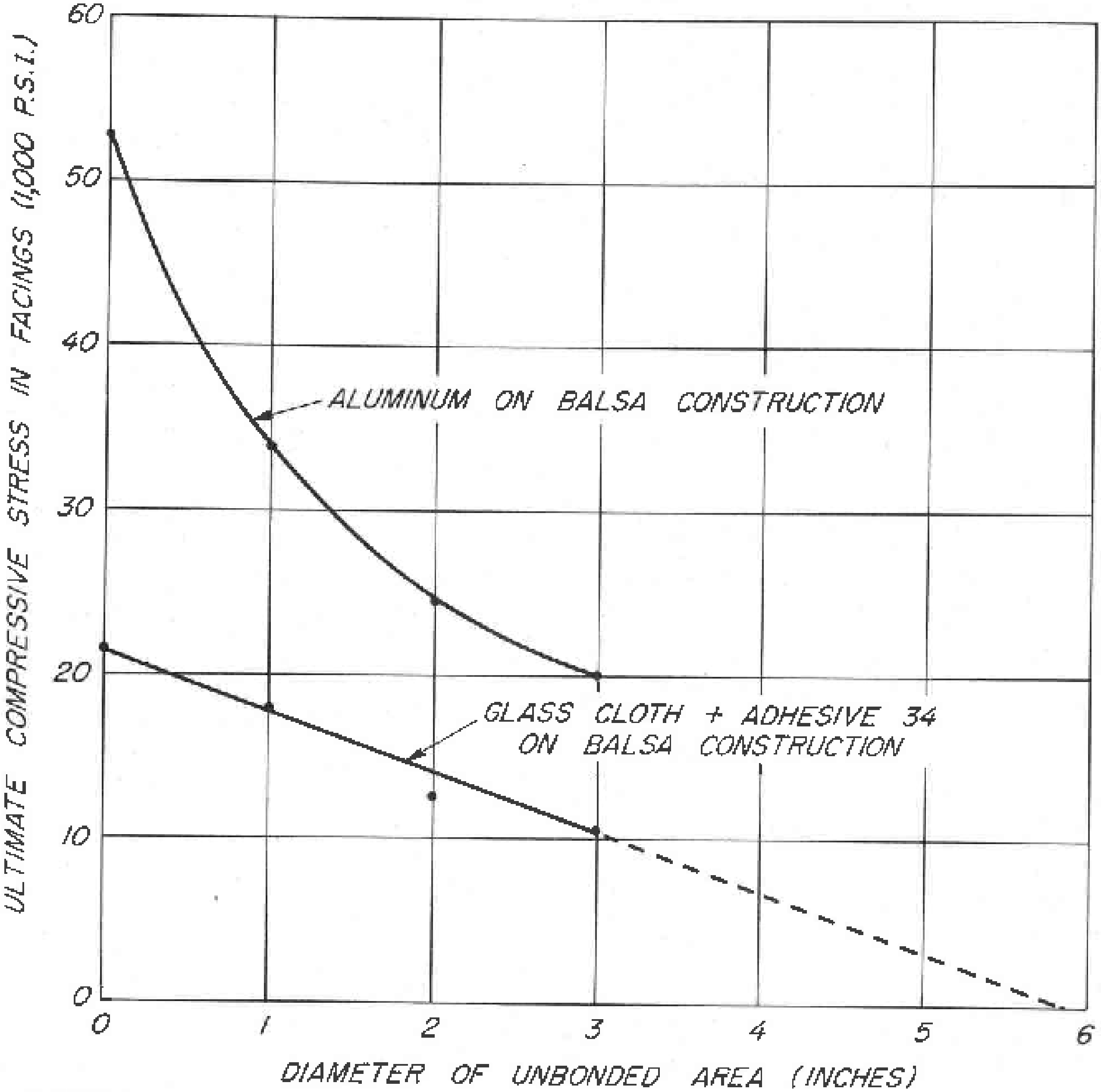

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Figure 5. --Relationship between the size of unbonded areas and ultimate facing stresses in sandwich panels tested in edgewise compression.