Supplement To

THE FLEXURAL RIGIDITY OF A RECTANGULAR STRIP OF SANDWICH CONSTRUCTION

Supplementary Mathematical Analysis and Comparison with the Results of Tests

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Supplement to

FLEXURAL RIGIDITY OF A RECTANGULAR STRIP OF SANDWICH CONSTRUCTION

COMPARISON BETWEEN MATHEMATICAL ANALYSIS AND RESULTS OF TESTS[1]

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Summary

The results of a number of bending tests made on several sandwich constructions are compared with values computed according to the mathematical analysis given in Forest Products Laboratory Report No. 1505,[3] and reasonable agreement is found. This analysis obviously does not give accurate results for certain extreme constructions. A new analysis is presented that should yield better results for these constructions. It is shown that the two analyses agree for usual constructions. Neither analysis is suitable for very short beams. It is also shown that if the modulus of rigidity of the core material is not uniform over the length of the beam, the use of the arithmetical average in the formulas will not yield proper results; a lesser value, dependent upon the amount of ununiformity, is required.

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

[3]"Flexural Rigidity of a Rectangular Strip of Sandwich Construction," by H.W. March and C. B. Smith. Forest Products Laboratory Report No. 1505.

Introduction

The mathematical development in Report No. 1505 (of which this report is a supplement) is based on a stress function in the form of a polynominal (see "Theory of Elasticity," chapter 2, by Timoshenko). The polynominal used (equation 10 of Report No. 1505) is the most general one that can be used.[4] The use of this polynominal limits the number of conditions that can be imposed at the clamped end of the cantilever beam to three and, of course, also imposes the conditions that the stress distributions across the clamped end of the cantilever be those derived from the stress function. In a test such stress distributions cannot be assured; but, according to St. Vennant's principle, the stress distribution at a distance from the clamped end is not disturbed by the particular statically equivalent stress distribution applied at the end.

The three conditions applied at the clamped end are given by equations (46), (47), and (48) of Report No. 1505. The application of these conditions yield reasonable numerical results, except when the modulus of rigidity of the core is exceedingly small or the facings are quite thick.

When two such cantilever beams are put together to form a single, centrally loaded beam, the longitudinal displacements at the central cross section of the beam should be zero at all points on the section as well as at the three positions indicated by equations (46), (47), and (48). The mathematical development in Report No. 1505 does not satisfy this condition; in fact a solution satisfying these conditions even for beams made of a solid isotropic material is not available.

The form of the equation for the effective stiffness (equation 65 in Report No. 1505) is such that when the modulus of rigidity of the core is reduced to zero, the effective stiffness is also reduced to zero. This is obviously incorrect for this extreme case, because the stiffness of the individual facings is still present. It is correct for the conditions expressed by equations (46), (47), and (48), and is numerically correct for the test conditions, as the tests indicate, except for the extreme constructions previously described.

A new mathematical analysis is given in the appendix of this report that may be applied to sandwich constructions having thick facings and cores of small moduli of rigidity. This analysis is based on certain simplifying assumptions that are made at the beginning of the analysis, which, just as in Report No. 1505, avoid an accurate description of the situation in the vicinity of the loads and reactions. They approximate the conditions in a test at positions in the specimen not too close to the loads or reactions. The effective stiffness obtained from this new analysis reduces to that of the individual facings when the modulus of rigidity of the core is reduced to zero. The equations derived from this analysis are shown to agree with those of Report No. 1505 for usual sandwich constructions, except for specimens tested on very short spans. For such specimens, neither analysis is suitable because all parts of the specimen are too close to the loads or to the reactions.

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[4] It would seem that a more general one could be used, but it is found that the coefficients of the added terms must be zero for the particular problem investigated.

It has been noted that the modulus of rigidity of the core of a sandwich construction determined from data from bending tests is usually less than that obtained from shear tests of the core material in which the shear strains are substantially uniform throughout the material. It is shown that this difference is due largely to variations in the modulus of rigidity of the core material along the specimen.

A considerable number of bending tests on various sandwich constructions were made, and the results were compared with those computed by the method of Report No. 1505. The agreement between the test and the computed values is reasonably good.

Description of Test Specimens

The test specimens were cut out of sandwich panels as shown in figures 1 and 2. Thirty such panels were used and 29 of them were numbered consecutively. The thirtieth panel was a duplicate of panel No. 8 and was numbered 8A. Each specimen was cut to a nominal width of 1 inch, and to a length noted on the specimen, as shown in figures 1 and 2. The lengths ranged from 36 to 6 inches. The specimens were arranged in duplicate pairs, with one of each pair being marked T and the other B. Each specimen number therefore consists of the number of the panel, the letter of a pair, and a number indicating the length. Thus the number 2T18 indicates the specimen marked T of the pair of 18-inch specimens cut from panel number 2.

The panels were made of various facing and core materials of various thicknesses. The facings on one side of panels 1 to 10 (excepting panels 4 and 7) were different in thickness from the facings on the other sides of these panels. Panels 11 to 29 had facings of the same thickness on each side. The facings were either glass-cloth laminates ranging from 0.006 to 0.024 inch thick, or aluminum ranging from 0.012 to 0.032 inch thick. The cores were end-grain balsa wood ranging from about 1/4 to 3/4 inch thick, cellular cellulose acetate ranging from about 1/4 to 1/2 inch thick, or paper honeycomb ranging from about 3/8 to 3/4 inch thick. The constructions of the various specimens are given in table 1.

The glass-cloth facings were made from a basket-weave, heat-cleaned glass cloth (No. 112-114), 0.003-inch thick, and a laminating resin of the polyester type (resin No. 1). The laminating was done directly on the core material (wet-laminating) with 40 to 45 percent of the resin.

The aluminum facings were 24ST clad conforming to specification AN-A-13. The dented, wrinkled, and contaminated sheets were eliminated by visual inspection.

The cellular, cellulose-acetate cores were made from extruded material containing about 3 percent of chopped glass fibers. The material, as received, was about 5/8 by 5-5/8 inches in cross section, from 4 to 10 feet long, and was covered by an outer skin that was removed prior to the manufacture of the core. The density of the remaining material ranged from 6.0 to 6.8 pounds per cubic foot. It was glued edge to edge to form the cores.

The balsa cores were made from wood having a density range from 5 to 8 pounds per cubic foot. The wood was conditioned to a moisture content (5 to 7 percent) substantially in equilibrium with the atmosphere of the workrooms. The individual boards were surfaced four sides and then cut across the grain into slices that were glued edge to edge to form the cores.

The paper honeycomb cores were made of 4.5-mil kraft paper by the method described in the appendix of NACA Technical Note No. 1529[5].

Specimens of the core materials matched as closely as possible to the core materials of the panels were obtained and were tested as subsequently described.

Description of Tests

The specimens were tested as beams. They were supported an inch from each end, and two equal, symmetrically placed loads were applied, as shown in figure 3. The specimens marked T were placed so that the marked facing was subjected to compression; those marked B were placed so that the marked facing was subjected to tension. The thicknesses of the facings with respect to these markings are given in table 1.

The deflections, over the complete span, of the specimens were read by means of a dial gage (0.001-inch minimum reading) as the loads were simultaneously applied. Thus load-deflection curves were obtained. The values of the maximum loads and descriptions of the failures were recorded.

Fine-wire resistance gages were affixed to the centers of the tension and compression facings at the centers of the specimens, and the strains were read at the various loads. Thus strain-load curves for the outside surfaces of each facing of each specimen were obtained.

The specimens of core material were tested in shear by the method described in Forest Products Laboratory Report No. 1555, page 13, starting with paragraph 36.[6]

Discussion of Mathematical Analyses

The mathematical analysis given in Forest Products Laboratory Report No. 1505[3] is exact; but it assumes that both facings are hinged at the positions of the loads and of the reactions, and that the shear stress is distributed across the core in certain ways at these positions (see Introduction). These assumptions are quite satisfactory for usual sandwich constructions. They are unsatisfactory only when:

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[5] "An Investigation of Mechanical Properties of Honeycomb Structures Made of Resin-impregnated Paper," by C. B. Norris and G. E. Mackin. National Advisory Committee for Aeronautics, Technical Note No. 1529.

[6] "Methods of Test for Determining the Strength Properties of Core Material for Sandwich Construction at Normal Temperatures." Forest Products Laboratory Report No. 1555. Revised 1948.

1. The modulus of rigidity of the core is exceedingly small.
2. The span of the beam is very short.
3. The facings of the sandwich are thicker than usual.
4. Conditions close to the loads and reactions are examined.

An approximate analysis in which this assumption is not made is given in the appendix of this report. The assumptions made in this analysis are:

1. The shear stress in the core is uniformly distributed across the core.
2. The stresses in the core, other than shear, are neglected.
3. The shear strains in the facings are neglected.
4. The curvatures of the two facings are assumed to be equal at any section of the sandwich.

This analysis should be reasonably accurate except in the neighborhood of the loads and of the reactions.

The following discussion compares the two analyses as applied to the tests described in this report. It is found that the two analyses are in close agreement except in the determination of the shear stress at failure in the sandwich beams tested over very short spans. For these beams it is likely that neither analysis yields results of sufficient accuracy because of the local effects of the concentrated loads and reactions.

The sandwich strips tested were supported near their ends and loaded at two positions equidistant from their centers as shown in figure 3. Load -- central-deflection curves were plotted. Strains at the top of the top facing and at the bottom of the bottom facing at the center of the beam were measured by means of metalectric strain gages and plotted against the load.

Central Deflections

The central deflection as given by the method of Forest Products Laboratory Report No. 1505[3] is:

$$W = \frac{Pb}{2D}\left[\frac{a^2}{2} + ab + \frac{b^2}{3}\left(1 + \eta\,\frac{h^2}{4b^2}\right)\right] \qquad (1)$$

in which the value of η is given by equation (73) and of $\underline{D}$ by equation (61) of that report. For usual sandwich construction the modulus of elasticity of the core is so small that the terms in these equations involving

$$\rho = \frac{E_c\,\lambda_f}{E_f\,\lambda_c}$$

in which E_c and E_f are the moduli of elasticity of the core and the facings, respectively, in the direction of the length of the strip, and λ_c and λ_f are the values of $(1 - \sigma_{xy}\,\sigma_{yx})$ associated with the core and facings, respectively;

in which σ_{xy} and σ_{yx} are Poissons ratios, may be neglected. Thus the value of D is the usual engineering value for the spaced facings:

$$D = \frac{E_f}{\lambda_f}\left[\frac{f_1^3 + f_2^3}{12} + \frac{f_1 f_2}{4}\frac{(h + c)^2}{h - c}\right] \qquad (2)$$

For similar reasons:

$$\eta = \eta_4 = \frac{6 E_f}{\lambda_f G_c}\frac{c f_1 f_2}{h^3}\frac{h + c}{h - c} \qquad (3)$$

from equation (77) of Report No. 1505[3], neglecting terms of which ρ is a coefficient. In this equation G_c is the modulus of rigidity of the core associated with strains in vertical planes parallel to the length of the sandwich strip.

The expression obtained for this deflection from the analysis given in the appendix of this report is:

$$W = \frac{Pb}{2D}\left[\frac{a^2}{2} + ab + \frac{b^2}{3}\right] + \frac{PbI_m}{2DI_f}\left[\frac{1}{\alpha^2} + \frac{\sinh\alpha d - \sinh\alpha(b + d) - \left[\cosh\alpha(a + b) - \cosh\alpha a\right]\sinh\alpha d}{b\alpha^3\cosh\alpha(a + b + d)}\right] \qquad (4)$$

where

$$\alpha^2 = \frac{G_c\,\lambda_f\,(f_1 + f_2)\,I}{E_f\,c f_1 f_2\,I_f}$$

$$I = \frac{f_1^3 + f_2^3}{12} + \frac{f_1 f_2}{4}\frac{(h + c)^2}{h - c}$$

$$I_f = \frac{f_1^3 + f_2^3}{12}$$

$$I_m = \frac{f_1 f_2}{4}\frac{(h + c)^2}{h - c}$$

These three moments of inertia (I, I_f, and I_m) are the usual engineering ones for the facings. The first is that for the spaced facings; the second is that for the facings taken alone; and the third is that due to the spacing of the facings.

The first term of equation (4) is the usual engineering formula for central deflection, and the second is the additional deflection due to shear strains in the core. As the modulus of rigidity of the core is increased, the second term approaches zero and the engineering formula remains. As the modulus of rigidity of the core is decreased, the value of the bracket in the second term approaches the value of the bracket in the first term so that when $G_c = 0$:

$$w = \frac{2P \lambda_f b}{E_f I_f} \left[\frac{a}{2} + ab + \frac{b^2}{3} \right]$$

which is the usual engineering formula for the central deflection of the two facings taken together but bending separately.

Equation (4) can be simplified in the range where $\tanh \alpha b$ is substantially unity, but G_c, and therefore α, is finite. The resulting equation is:

$$w = \frac{Pb}{2D} \left[\frac{a^2}{2} + ab + \frac{b^2}{3} \right] + \frac{Pb}{2G_c} \frac{I_m}{I^2} \frac{f_1 f_2 c}{(h - c)} \left\{ 1 + \frac{1}{b\alpha} \left[e^{-\alpha a} + \frac{1}{2} \left(1 - e^{-2\alpha d}\right) \right] \right\} \quad (5)$$

This equation is applicable to specimen 9T-6, which had aluminum facings and a cellular cellulose-acetate core. By assuming $E_f = 10{,}000{,}000$ and by determining values of G_c from the experimental load-deflection curve of the specimen by means of equations (1) and (5), it is found that equation (5) yields a value 9 percent greater than equation (1). This percentage is greatly reduced for balsa wood or for the usual honeycomb-core materials. Thus the two analyses (that from Report No. 1505 and that from the appendix of the present report) yield substantially the same results for usual core materials, even for the short span over which the specimen was tested. The agreement of the two methods is much closer for specimens tested over longer spans.

Mean Values of the Modulus of Rigidity of the Core

In the derivations of equations (1) and (4) it was assumed that the modulus of rigidity of the core is constant along the length of the beam. Since the core materials are never absolutely uniform, this assumption is not strictly true, particularly for balsa-wood cores. The value of G_c that should be used in these equations is, therefore, a sort of mean value that is not necessarily the arithmetical average. The general expression for this mean value is, of course, the average shear stress divided by the average shear strain, or:

$$\bar{G} = \frac{\frac{1}{l}\int_0^l \tau \, dx}{\frac{1}{l}\int_0^l \gamma \, dx} \quad (6)$$

where τ and γ are the shear stress and the shear strain, respectively, and the integrations are taken over the length of the specimen. If the facings are thick and have large elastic properties compared to the core, the value of the shear strain is substantially constant along the specimen and equation (6) yields

$$\bar{G} = \frac{1}{l}\int_0^l G\,dx$$

which is the arithmetical average of the modulus of rigidity of the specimen. On the other hand, if the facings are very thin so that they carry very little of the shear load applied to the specimen, and because the shear load is constant along the specimen, the shear stress is substantially constant along the specimen. Thus equation (6) yields:

$$\bar{G} = \frac{1}{\frac{1}{l}\int_0^l \frac{1}{G}}$$

which is the reciprocal of the average reciprocal values of the modulus of rigidity.

These two equations yield the same result if the modulus of rigidity does not vary along the specimen. If it does vary, the second one always yields lesser values than the first. The value obtained from any particular test lies between these two values. It follows that if average values of the shear modulus are desired, thick facings should be used; however, this may require the use of equation (4) rather than equation (1). This difficulty can be avoided by using the standard test described on page 13 of Forest Products Laboratory Report No. 1555.[6] In this way average values of modulus of rigidity are measured; but these values should be reduced for design purposes, depending upon the variability of the modulus of rigidity and of the facing thickness.

A similar argument applies to shear strength. If the modulus of rigidity varies along the specimen, the shear strength is likely to vary in a similar manner, being small where the modulus is small and large where the modulus is large. In the standard shear test[6] the shear strain is substantially constant along the specimen. Thus the shear stress is small where the modulus is small, that is, where the shear strength is small. The shear stress is relieved where the core material is weak, and failure does not take place so readily in these locations as it would if this were not the case. On the other hand, if the facings are thin and if the specimen is tested as a centrally loaded beam, the shear stress in the core is substantially constant along the specimen and failure will take place at the point of minimum shear strength. Such a test will, therefore, always yield a lesser shear strength than does the standard test if the shear strength varies along the specimen.

In the present state of the art it seems advisable to use values of modulus of rigidity and shear strength of core materials obtained from bending tests in formulas involving flexure even though such values may be influenced by the particular sandwich construction tested. Flexure is involved when the sandwich panel is bent in planes perpendicular to its surface as in bending and buckling. It is not involved in face wrinkling, in stress concentrations in the core, and like instances.

Shear Stress in the Core

The maximum shear stress in the core may be found by the method of Forest Products Laboratory Report No. 1505.[3] This method leads to a parabolic distribution of shear across the thickness of the core. For sandwich constructions having facings of equal thickness, the maximum value of shear stress is at the center of the core. For usual sandwich constructions this value decreases only slightly toward the facings. For sandwich constructions having unequal facing thicknesses, the mathematical maximum value may lie outside of the core; then the true maximum value is that at the junction of the core with the thicker facing. This value is given by:

$$\tau_1 = \frac{P}{2}\ \frac{6f_1\left[f_2(h + c) + \rho c(c + f_1)\right]}{12\ chf_1f_2 + (h - c)^4 + 2\rho c\left\{(h - c)\left[2h^2 - c(h - c)\right] - 6hf_1f_2\right\} + \rho^2c^4} \qquad (7)$$

In this equation f_1 is the thickness of the thicker facing and f_2 that of the thinner facing. Equation (7) yields the shear stress at the junction of the core with the thinner facing (τ_2) if the subscripts 1 and 2 are interchanged.

Usually the value of ρ is so small that the terms involving it may be neglected and equation (7) becomes:

$$\tau = \frac{P}{2}\ \frac{6f_1f_2\ (h + c)}{12\ chf_1f_2 + (h - c)^4} \qquad (8)$$

This equation applies at the junction between the core and either facing, since interchanging the subscripts does not change its value. It follows (not directly) that neglecting the terms involving ρ is consistent with the assumption that the shear stress is constant across the core.

If the two facings are of equal thickness, equation (8) reduces to:

$$\tau = \frac{P}{4}\ \frac{h + c}{c^2 + 2cf + \frac{4}{3} f^2}$$

If the facings are thin compared to the core thickness, the term $\frac{4}{3} f^2$ may be replaced by f^2 and the equation reduces to:

$$\tau = \frac{P}{h + c} \qquad (9)$$

which is a formula often used in design. This formula is a remarkably good approximation of equation (7) over wide ranges of facing thicknesses and values of ρ. For specimen 9T-6, which has aluminum facings, one of them about 2-1/2 times the thickness of the other, and a cellular cellulose-acetate core, equation (7) yields a shear stress only 2 percent greater than equation (9).

The method of analysis given in the appendix also supplies a formula for the shear stress in the core. For span b it is:

$$\tau = \frac{P}{h + c} \frac{I_m}{I} \left[1 - \frac{\sinh \alpha d \ \sinh \alpha(a + x) + \cosh \alpha(b + d - x) \cosh \alpha a}{\cosh \alpha(a + b + d)} \right] \quad (10)$$

in which x is the distance from the right-hand load to the section in question as shown in figure 3.

Thus the shear stress is not constant along this span even though the total shear load on the beam is constant. The division of the total shear between the core and the facings changes along the span. Similar formulas for the central span and the overhang show that the shear stress is not zero in these spans but is maximum at the position of the load or reaction and, for large values of α decreases rapidly toward the interior of the spans.

As the modulus of rigidity of the core increases or the thicknesses of the facings decrease, the value of α increases and the right-hand member in the bracket of equation (10) approaches zero and equation (10) becomes

$$\tau = \frac{P}{h + c} \frac{I_m}{I} \quad (11)$$

which, for thin facings, is substantially the same as equation (9). This value prevails over the length of span b of the specimen except in the immediate neighborhood of the loads and of the reactions, where it is reduced.

If equation (10) is applied at the middle of span b ($x = \frac{b}{2}$) and if $\frac{\alpha b}{2}$ is large enough so that its hyperbolic tangent is substantially unity $\left(\frac{\alpha b}{2} = 2.6 \text{ or greater} \right)$, equation (10) can be approximately written:

$$\tau = \frac{P}{h + c} \frac{I_m}{I} \left(1 - e^{-\frac{\alpha b}{2}} \right) \quad (12)$$

This equation applies to specimen 9T-6 below the proportional limit in shear of the core material where the modulus of rigidity is about 5,000. By applying this equation to this specimen, the shear stress is found to be about 1/2 percent less than that given by equation (9).

The shear stress in span b under these conditions is substantially constant along the span except in the neighborhood of the load and the reaction, and the maximum value is near the midpoint of the span. As the shear stress increases, however, and the proportional limit is exceeded, the average modulus of rigidity decreases because the tangent modulus of rigidity is operative. By using the tangent modulus of failure of 775 pounds per square inch from figure 2 of Forest Products Laboratory Report No. 1815[7] in equation (10), it is found that the shear

[7]"Effect of Shear Strength on Maximum Loads of Sandwich Columns," by K. H. Boller and C. B. Norris. Forest Products Laboratory Report No. 1815.

stress is about 13 percent less than that given by equation (9). Thus equation (9) does not give the true shear strength for beams tested on such short spans, and the shear strengths of these short beams were, therefore, omitted from the analysis of the experimental data. Of course this method of obtaining the 13 percent value is approximate. The entire stress-strain curve of the core material should have been used rather than only the tangent modulus at failure.

Bending Stress in the Facings

The bending stresses in the facings of span b, according to the method of Forest Products Laboratory Report No. 1505,[3] are given for the compression facing by:

$$\sigma_1 = -\frac{PE_f}{2\lambda_f D}(b - x)\left[\frac{1}{2}\,\frac{f_2\,(h + c) + \rho c\,(f_1 + c)}{h - c + \rho c} + y_1\right] \qquad (13)$$

and for the tension facing by:

$$\sigma_2 = \frac{PE_f}{2\lambda_f D}\,(b - x)\left[\frac{1}{2}\,\frac{f_1\,(h + c) + \rho c\,(f_2 + c)}{h - c + \rho c} - y_2\right] \qquad (14)$$

in which f_1 and f_2 are the thicknesses of the compression and the tension facings, respectively; y_1 and y_2 are vertical distances from the centers of the compression facing and tension facing, respectively, measured positively upward; and $\underline{D}$ is given by equation (61) of Report No. 1505.

If the terms involving ρ are neglected, these equations become:

$$\sigma_1 = -\frac{P}{2I}\,(b - x)\left(\frac{f_2}{2}\,\frac{h + c}{h - c} + y_1\right) \qquad (15)$$

$$\sigma_2 = -\frac{P}{2I}\,(b - x)\left(\frac{f_1}{2}\,\frac{h + c}{h - c} - y_2\right) \qquad (16)$$

If the facings are sufficiently thin so that the cubes of their thicknesses may be neglected ($I = I_m$), these equations become:

$$\sigma_1 = -\frac{P}{2}\,(b - x)\left[\frac{2}{f_1\,(h + c)} + \frac{4y_1}{f_1 f_2}\,\frac{h - c}{(h + c)^2}\right]$$

$$\sigma_2 = \frac{P}{2}\,(b - x)\left[\frac{2}{f_2\,(h + c)} - \frac{4y_2}{f_1 f_2}\,\frac{h - c}{(h + c)^2}\right]$$

Because the bending stresses vary linearly across the facings, the average stresses in the facings are given by these equations when y_1 and y_2 are zero. Thus:

$$\bar{\sigma}_1 = - \frac{P\ (b - x)}{f_1\ (h + c)} \tag{17}$$

$$\bar{\sigma}_2 = \frac{P\ (b - x)}{f_2\ (h + c)} \tag{18}$$

which are the expressions obtained by equating the internal and external bending moments in the usual approximate analysis.

In most sandwich constructions equations (17) and (18) yield excellent approximations of the maximum bending stresses at bending failure, because at these high stresses the stress is almost independent of the strain and, therefore, the stress is almost constant across the facings.

The bending stresses in the facings, in span b, can also be computed by the analysis given in the appendix of this report. The equations are:

$$\sigma_1 = - \frac{P}{2I}(b - x)\left[\frac{f_2}{2}\ \frac{h + c}{h - c} + y_1 - \left(\frac{f_2}{2}\ \frac{h + c}{h - c} - \frac{I_m}{I_F}y_1\right)\frac{\sinh \alpha (b + d - x)\ \cosh \alpha a - \cosh \alpha (a + x)\ \sinh \alpha d}{(b - x)\ \alpha\ \cosh \alpha (a + b + d)}\right] \tag{19}$$

and

$$\sigma_2 = \frac{P}{2I}(b - x)\left[\frac{f_1}{2}\ \frac{h + c}{h - c} - y_2 - \left(\frac{f_1}{2}\ \frac{h + c}{h - c} + \frac{I_m}{I_F}y_2\right)\frac{\sinh \alpha (b + d - x)\ \cosh \alpha a - \cosh \alpha (a + x)\ \sinh \alpha d}{(b - x)\ \alpha\ \cosh \alpha (a + b + d)}\right] \tag{20}$$

As the modulus of rigidity of the core increases or the thickness of the facings decreases, α becomes large and the fraction in the right-hand member approaches zero; thus these equations approach equations (15) and (16), respectively, which were obtained from the method of Report No. 1505.[2] For most practical sandwich constructions the two sets of equations yield substantially identical results.

If the modulus of rigidity of the core, and therefore α, becomes zero, the fraction in the right-hand member becomes unity and these two equations become:

$$\sigma_1 = - \frac{P}{2\,I_f} (b - x)\, y_1$$

$$\sigma_2 = - \frac{P}{2\,I_f} (b - x)\, y_2$$

which give the stresses in the facings acting as two separate beams subject to the same deflection.

If α has such a value that $\tanh \frac{\alpha b}{2}$ can be considered to be unity ($\frac{\alpha b}{2}$ = 2.6 or greater), equations (19) and (20) become:

$$\sigma_1 = - \frac{P}{2I} (b - x) \left[\frac{f_2}{2}\,\frac{h + c}{h - c} + y_1 - \left(\frac{f_2}{2}\,\frac{h + c}{h - c} - \frac{I_m}{I_F}\, y_1 \right) \frac{e^{-\alpha x} - e^{-\alpha (b - x)}}{2\,\alpha (b - x)} \right] \quad (21)$$

$$\sigma_2 = \frac{P}{2I} (b - x) \left[\frac{f_1}{2}\,\frac{h + c}{h - c} - y_2 - \left(\frac{f_1}{2}\,\frac{h + c}{h - c} - \frac{I_m}{I_F}\, y_2 \right) \frac{e^{-\alpha x} - e^{-\alpha (b - x)}}{2\,\alpha (b - x)} \right] \quad (22)$$

These equations yield values identical to equations (15) and (16), respectively, when $x = \frac{b}{2}$, and values not far from them for other values of x. For specimen 9T-6, which has aluminum facings and a cellular cellulose-acetate core and which was tested over a short span, equations (21) and (22) agree with equations (15) and (16) within 5 percent when the shear stress in the core is less than the proportional limit, and within 13 percent when the core is about to fail in shear. It follows that, for usual sandwich constructions, equations (17) and (18) agree reasonably well[1] with this analysis as well as with the analysis given in Report No. 1505.[2]

Presentation and Discussion of Results of Tests

The results of the individual tests and computations are given in table 1. The first column gives the specimen number. The second and third columns give the lengths of spans a and b as shown in figure 3. Span d has a length of 1 inch for all the specimens tested. The fourth column gives the thickness of the upper facing, that is, the facing subjected to compression. The fifth column gives the slope of the straight portion of the load-deflection curve, with the deflections being taken at the center of the beam and plotted against the total load. The sixth column gives values of the expression $\frac{h^2}{4b^2}$ computed from equation (1) when using equation (2) for the computation of D. In the latter equation the value of $\frac{E}{\lambda}$ for aluminum was taken as 11 million and for glass-fabric laminate as 2.866 million. The latter figure was taken from Forest Products

Laboratory Report No. 1583-A.[8] (The strips of sandwich panels having eight-ply fabric laminated facings reported in the present report were cut from the panels reported in Report No. 1583-A. It happens that the moduli of rigidity computed from strips having thinner glass-fabric laminated facings were eliminated from the averages for reasons subsequently given.) It may be noted that the value of the expression $\eta \frac{h^2}{4b^2}$ is obtained from the difference of two values that are nearly equal for some specimens. The values of modulus of rigidity obtained from these small differences is far from accurate. For this reason, if the computed value of this expression is less than 0.4 its accuracy is doubtful. The seventh column gives the moduli of rigidity of the cores obtained from equation (3). The values chosen for averaging are marked with a letter g. The values obtained from the beams having a 6-inch span were arbitrarily discarded because equation (1) does not apply in the neighborhood of the loads or of the reactions. For the same reason, values obtained from the expression $\eta \frac{h^2}{4b^2}$ greater than 3.0 were discarded. Values obtained from values of this expression less than 0.4 were discarded for the reason previously given. These two limits of the expression were roughly determined from a general examination of the computed values in column seven; the choice of 0.4 and 3.0 seems to eliminate all of the "wild" values of modulus of rigidity.

The eighth column gives the maximum loads applied to the beams. Most of these loads were sufficient to cause failure; however, some of them caused such large deflections that the test was discontinued. The ninth column lists the types of failure noted as the test was made. The term "comp" means a compressive failure in the upper facing. The word "wrinkle" means a compressive failure in the upper facing, which might be due to wrinkling of the facing rather than from compression; the word "tension," a tension failure in the lower facing; and the word "shear" means a shear failure in the core. The word "none" means that the test was discontinued, because of excessive deflection, before failure occurred. These observations of the types of failure were revised after the computed stresses were obtained. The revisions are shown by letters placed after the stress values in other columns as subsequently described.

The tenth column gives the stress in the thinner facing as computed by the use of equations (17) and (18) when placing x equal to zero. The type of failure is indicated by the small letter placed after each value. These letters are abbreviations of the words in column 9, but they do not necessarily agree with them. For example, column 9 indicates that specimen 1B18 did not fail and column 10 indicates that it did fail at a tensile stress of 31,000 pounds per square inch. This value of stress is greater than that computed for other specimens in the same group that did fail in tension. Thus it was concluded that if the test of specimen 1B18 had been continued, it would have failed at substantially the stress of 31,000 pounds per square inch. That is, the facing was stressed approximately to its ultimate stress and was stretching so badly that the test had to be discontinued due to excessive deflection. A similar situation is shown for specimen 2B8. Column nine indicates a shear failure; but the tensile stress

[8] "Effects of Shear Deformation in the Core of a Flat Rectangular Sandwich Panel," W.J. Kommers and C.B. Norris, Forest Products Laboratory Report No. 1583-A.

of 39,900 pounds per square inch is so large that it is assumed that this specimen failed primarily in tension and that the apparent shear failure was secondary. The shear stress given in column 11 does not seem great enough to cause failure.

The eleventh column gives the shear stress in the core computed by means of equation (9). The small letter "s" placed after these values indicates the specimens deemed to have failed in shear. These indications do not always agree with the observations noted in column nine for reasons similar to those already given. Sometimes (note specimen 5T12) it could not be determined whether the primary failure was in the core or the facing. It was assumed, for these specimens, that the failure occurred simultaneously in both places.

The strains in the facings between the two loads were measured as previously described. Very often the strains of the maximum load were not obtained, and the last strain reading was taken at a slightly lesser load. The twelfth and thirteenth columns give the stresses in the facings, computed by equations (17) and (18), at these lesser loads, and the fourteenth and fifteenth columns give the values of the measured strains. The sixteenth and seventeenth columns give the stresses associated with these strains and were obtained from stress-strain curves for the facing materials. The stress-strain curves for the aluminum facings were taken from the National Advisory Committee for Aeronautics Technical Note No. 1512,[9] and are shown in figure 4. Those for the glass-fabric laminate facings are average curves taken from the original data of Forest Products Laboratory Report No. 1821[10] for the glass fabric used in the present report, and are shown in figure 5. When the recorded strains exceeded the limits of these curves, the stress values were omitted from columns 16 and 17.

For purposes of analysis, the data given in table 1 are collected in summary tables giving average values for the various groups of specimens. In tables 2 and 3 the stresses obtained from equations (17) and (18) are compared with those obtained from the stress-strain curves and the measured strains. These tables indicate that the computed stresses are substantially equal to the stresses obtained from the strains. It is possible that the stress-strain curves used were not quite proper for the particular materials tested.

All of the data on the compressive strength of the glass-fabric laminate are collected in table 4. The values averaged are those in column 10 of table 1 that are followed by the letter "c." Table 4 indicates that the compressive strength is substantially independent of the facing and core thicknesses over the limits of the experimental data; also that the facings have substantially the same strength whether they are laminated on balsa wood or on cellular cellulose-acetate cores, but seem to have a greater strength when they are laminated on the paper honeycomb cores. This table also gives values from Forest Products Laboratory Report No. 1821[10] on the same type of glass-fabric laminate made between metallic platens. The compressive strength of the facings seems about equal to the proportional limit stress of the material of Report No. 1821. From the results of other work now in progress it seems that the lesser strength is obtained when the facings are made by the "wet laminating" process.

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[9] "Stress-strain and Elongation Graphs for Alclad Aluminum Alloy 24-ST Sheet," by James A. Miller, N.A.C.A. Tech. Note 1512.

[10] "Mechanical Properties of Cross-laminated and Composite Glass-fabric-base Plastic Laminates," by Alan D. Freas and Fred Werren. Forest Products Laboratory Report No. 1821.

Table 5 is a similar table for the compressive strength of the aluminum facings. The strengths of the facings supported by balsa-wood and by cellular cellulose-acetate cores agree reasonably well with the strengths obtained from edgewise compressive tests on similar sandwich constructions reported in Forest Products Laboratory Report No. 1810,[11] but they do not follow the curves given in that report. This might be expected because the conditions under which the face wrinkling occurs are quite different. The compressive strength of the facings bonded to the paper honeycomb core is limited by the critical stress of the small plates of facing bounded by the cell walls of the honeycomb. This critical stress was computed by the method of Forest Products Laboratory Report No. 1817[12] and the computed values were entered in the table. These stresses only roughly agree with those obtained in the bending tests. The fact that the thicker facings yield lesser values of compressive strength has not been explained.

A few data were obtained on the tensile strength of the facing materials from the few specimens that failed in tension. These data are given in tables 6 and 7. The values are those in column 10 of table 1 that are followed by the letter "t." The tensile strengths of the glass-fabric laminate agree well with those given in Forest Products Laboratory Report No. 1821,[10] which are also entered in table 6. The tensile strengths of the aluminum are substantially the same as those given in National Advisory Committee for Aeronautics Technical Note No. 1512[9], which are also entered in table 7.

Tables 8, 9, and 10 give average values of shear strength and modulus of rigidity of the three core materials used: balsa wood, cellular cellulose acetate, and paper honeycomb, respectively. Columns one to four of these tables identify the specimen groups and give the thicknesses of the facings and cores. Column 5 gives the average shear strengths, computed by means of equation (9), excluding specimens 6 and 8. The values averaged are those from column 11 of table 1 that are followed by the letter "s." Column 6 gives the number of tests associated with the averages in column 5. Columns 4 and 8 give the averages for specimens 8 and the associated number of tests, respectively. Column 9 gives the shear strength obtained from shear tests according to the method of Forest Products Laboratory Report No. 1555,[6] page 13, starting with paragraph 36, on core material matched to that used in the bending tests, when this material was available. The values in column 10 are the ratios of those in column 9 to those in column 5.

Column 11 gives average values of the moduli of rigidities taken from column 7 of table 1. The values used were those followed by the letter "g." Column 12 gives the number of tests associated with the values in column 11. Column 13 gives the values of modulus of rigidity obtained from the shear tests, and column 14 gives the ratios of those in column 13 to those in column 11.

A comparison of the values in columns 5 and 7 in these three tables show that the computed shear strengths obtained from specimens 8 are, in general, greater than

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[11]"Wrinkling of the Facings of Sandwich Construction Subjected to Edgewise Compression," by Charles B. Norris, Wilhelm S. Ericksen, H. W. March, C. B. Smith, and Kenneth H. Boller. Forest Products Laboratory Report No. 1810.

[12]"Short-column Compressive Strength of Sandwich Constructions as Affected by the Size of the Cells of Honeycomb-core Materials," by C. B. Norris and W. J. Kommers. Forest Products Laboratory Report No. 1817.

those obtained from the other specimens (excluding specimens b). This is due to the transfer of shear from the core to the facings, in these short specimens, as the shear stress approaches its maximum value, as previously discussed.

The values in columns 10 of these tables show that the shear test yields greater shear strengths than the beam tests. As previously discussed, this is due to the variation in shear strength along the specimen. In the beam test, the core tends to fail at the location of its weakest shear strength, while in the shear test the shear strain is substantially constant along the specimen and, thus, the shear strength is more nearly equal to the average strength of the specimen. The average values in column 10 indicate that the balsa wood is most variable in shear strength (ratio 1.42), the paper honeycomb core is the least variable (ratio 1.23), and the cellular cellulose acetate is between the two (ratio 1.34).

The values in columns 14 of these tables show that the modulus of rigidity obtained from the shear test is greater than that obtained from the beam test. As previously, said, this is due, at least in part, to the variation of the modulus along the specimens. The shear test yields a modulus, that is the average for the specimen, while the beam test yields a lesser value. The average values in column 14 show the modulus to be most variable for the honeycomb core (ratio 1.78). The modulus probably varies across the individual cells of the honeycomb. The modulus is least variable for the cellular cellulose acetate (ratio 1.06), and the balsa wood is intermediate (ratio 1.46). The number of specimens reported in table 1 and available for this comparison is small. More data are given from supplementary tests.

Supplementary Tests

In the series of tests reported in table 1, only a limited number of tests are available for the comparison of the modulus of rigidity of the core material obtained by means of the beam test with that obtained by the shear test. Further data, from another study, are, therefore, included. Also, data from two tests in which the modulus of rigidity was measured at particular locations in a centrally loaded beam are given.[13]

Comparison of Moduli of Rigidity Obtained from Beam Tests with Those Obtained from Shear Tests

In connection with another investigation, moduli of rigidity were obtained from strips of sandwich construction tested as centrally loaded beams and also from shear tests made on specimens reasonably well matched to the strips. The results of these tests are given in table 11, in which column 1 gives the specimen number, column 2 the results of the beam tests, and column 3 the results of the shear tests. Each of the values in column 2 represents the average of the results from two bending specimens; thus each specimen number applies to four specimens. Each of the values in column 3 represents the result from a single shear test.

[13] These two tests were performed by A. W. Voss, engineer, at the Forest Products Laboratory.

The bending tests were conducted as described in Forest Products Laboratory Report No. 1556[14] (revised February 1950), page 7, and the modulus of rigidity was computed by use of the appropriate formulas on page 9 of that report. The facings were all 0.02-inch aluminum. The core materials and thicknesses are given in the table. Various spans were used; the ranges of values of $\eta \frac{h^2}{4b^2}$ are given in table 11.

The shear specimens having balsa-wood cores were cut from the panels from which the bending specimens were obtained, and were tested as described in Forest Products Laboratory Report No. 1556[14] (revised February 1950), page 12, and the modulus of rigidity was computed according to the appropriate formula on page 13 of that report, neglecting the first term in the right-hand member. The other shear specimens were obtained from core material matched to the panels from which the bending specimens were obtained and were tested as described in Forest Products Laboratory Report No. 1555[6] (revised October 1948), page 13, and the modulus of rigidity was computed accordingly.

It may be noted that some of the values of $\eta \frac{h^2}{4b^2}$ are outside of the limits previously set, and thus some of the values of modulus of rigidity obtained from the beam tests may not be accurate. The average values, however, should be reasonably accurate. There is considerable variation in the individual values.

The modulus of rigidity of the balsa wood obtained from the shear test is, on the average, 33 percent greater than that obtained from the beam test. This is probably due to the variability of the balsa wood as previously discussed. The moduli of rigidity of the hard sponge rubber and of the cellular cellulose acetate obtained from the shear test are, on the average, only 15 percent greater than those obtained from the bending test. This is an indication that these materials are more uniform than the balsa wood.

Measurement of the Modulus of Rigidity at a Particular Location in a Centrally Loaded Strip of Sandwich Construction

Figure 6 shows a method of test devised to determine the modulus of rigidity of the core of a strip of sandwich construction at a particular location. The strip was tested as a centrally loaded beam, as shown. At a position in the span of the beam three mirrors were mounted. The outer two mirrors were mounted on very light C-clamps made of wire, the ends of which were filed to form knife edges bearing on the outer surfaces of the facings. The central mirror was mounted on a wire soldered to the outer surface of the upper facing. The shadow of a cross hair was projected on these mirrors, and its reflection was read on suitable scales. The relative longitudinal movement of the two facings was determined by the differences of the angular movement of the two outer mirrors compared with that of the central mirror. Similar mirrors were placed at the

[14] "Methods for Conducting Mechanical Tests of Sandwich Construction at Normal Temperatures." Forest Products Laboratory Report No. 1556. Revised February 1950.

other end of the beam in a similar position. These mirrors are hidden, in the figure, by a cardboard shield required to keep the two light sources from interfering. The modulus of rigidity of the core material was obtained by dividing the shear stress obtained from equation (9) by the shear strain obtained from the mirrors.

Several tests were made on a single specimen, each test with the mirrors at a different location. Two specimens were used, both having aluminum facings 0.032 inch thick. The first specimen had a cellular cellulose-acetate core 0.489 inch thick, and the second had an end-grain balsa-wood core 0.505 inch thick. The span for each specimen was 24 inches.

After the specimens were tested, they were each cut into four shear specimens and tested as described in Forest Products Laboratory Report No. 1556[14] (revised February 1950), page 12.

The shear stress in the core at the location of the mirrors was obtained from equation (9), and the moduli of rigidity obtained from the central deflections was computed from equations (1), (2), and (3) by placing _a_ equal to zero.

The moduli of rigidity computed from data taken from the first specimen are given in table 12. The modulus of rigidity obtained from the deflection of the beam was substantially the same from the three tests and is 3,830 pounds per square inch. The value of $\eta \frac{h^2}{4b^2}$ for this test is 0.441, which indicates that the value of the modulus is reasonably reliable.

Similar data taken from the second specimen are given in table 13. The modulus of rigidity taken from the deflection readings is 15,860 pounds per square inch. The value of $\eta \frac{h^2}{4b^2}$ is 0.115, which indicates that this value for the modulus is not very reliable.

These are results of individual tests and, therefore, rigid conclusions should not be drawn from them. The cellular cellulose-acetate core shows some variability (from 0.792 to 1.123). The balsa-wood core shows a greater variability (from 0.644 to 1.655). For the cellular cellulose acetate, the average value obtained from the mirrors is substantially that obtained from the deflection measurements, which indicates uniformity of the material. The nonuniformity of the balsa wood is indicated by the difference in the values obtained in these ways.

Conclusions

1. The results of the new analysis agree with that of Report No. 1505 for usual sandwich constructions. For extreme sandwich constructions having thick facings and cores of very small moduli of rigidity, the new analysis may yield values closer to those existing in the specimens. Neither analysis is suitable for very short specimens, nor for the determinations of the stresses near the loads or reactions.

2. The modulus of rigidity of the core that is effective in a bending test of a sandwich specimen is not the arithmetical average of the modulus for the material of the core, but a lesser value. The decrease is largely due to variation in the modulus along the specimen, and it will not exist if the core material is absolutely uniform. It seems advisable to use values of modulus of rigidity and shear strength of core materials obtained from bending tests in formulas involving flexure even though such values may be influenced by the particular sandwich construction tested.

3. In general, the values obtained from tests agree reasonably well with those computed by the method of Report No. 1505.

APPENDIX

In the following analysis of a sandwich beam subjected to normal loads, the facings are treated as cylindrically bent plates. The strains in the facings are taken to consist solely of those associated with bending and stretching, and it is assumed that the component of normal displacement is identical in the two facings. The thicknesses of the two facings, denoted by f_1 and f_2, may be equal or unequal. It is convenient to identify a facing as 1 or 2 accordingly as its thickness is f_1 or f_2.

The core material is considered to be weak in shear and in bending stiffness as compared with the facing material. The bending stiffness of the core is neglected entirely, and the stiffness of the strip is therefore taken to be that of the two facings separated by a material that offers no resistance to bending. In the analysis of the shear in the core, it is assumed that the shear deformations are constant over the thickness of the core.

Conditions for Equilibrium

An element of each of the two facings of the sandwich is shown in figure 7. The facings are taken to be of unit width, and the symbols F, S, and M denote the resultant longitudinal force, shear force, and bending moment, respectively, acting on a normal section. Subscripts 1 and 2 are used to refer these resultants to facings 1 and 2, respectively. The symbol τ denotes the shear stress transmitted by the core to the facings.

With reference to figure 7, which indicates the sign conventions used for forces and moments, the following condition for equilibrium of the two facings are derived:

Longitudinal forces,

$$\left.\begin{aligned} \frac{dF_1}{dx} - \tau &= 0 \\ \frac{dF_2}{dx} + \tau &= 0 \end{aligned}\right\} \text{------------------(1)}$$

Normal forces,

$$\left.\begin{aligned} \frac{dS_1}{dx} - \sigma_1 + F_1 \frac{d^2w}{dx^2} &= 0 \\ \frac{dS_2}{dx} + \sigma_2 + F_2 \frac{d^2w}{dx^2} &= 0 \end{aligned}\right\} \text{------------------(2)}$$

Moments,

$$\left.\begin{aligned} \frac{dM_1}{dx} - S_1 + \frac{\tau f_1}{2} = 0 \\ \frac{dM_2}{dx} - S_2 + \frac{\tau f_2}{2} = 0 \end{aligned}\right\} \text{------------------(3)}$$

Equations (1) neglect the longitudinal components of the shear forces in the facings. Equations (2) are written on the assumption that the curvatures of the two facings are the same.

The normal force equilibrium of an element of the core is stated by the condition,

$$\frac{d}{dx}(c\tau) + \sigma_1 - \sigma_2 = 0 \qquad (4)$$

It is assumed that the core is not subjected to longitudinal forces or to moments.

The equilibrium conditions for the sandwich element as a whole are obtained by combining equation (1) for longitudinal forces, (2) and (4) for normal forces, and (3) for moments. These are written

$$\frac{d}{dx}(F_1 + F_2) = 0 \qquad (5)$$

$$\frac{d}{dx}(S_1 + S_2 + c\tau) + (F_1 + F_2)\frac{d^2w}{dx^2} = 0 \qquad (6)$$

and

$$\frac{d}{dx}(M_1 + M_2) - (S_1 + S_2) + \left(\frac{f_1 + f_2}{2}\right)\tau = 0 \qquad (7)$$

According to (5), $F_1 + F_2$ is constant. Now if the supports do not transmit longitudinal resultants to the sandwich, and since there are no end loads, the constant is zero and, consequently,

$$F_1 + F_2 = 0 \qquad (8)$$

throughout the beam. This relation is assumed in the analysis.

The Components of Displacement in the Facings and of Shear Strain in the Core

The components of normal displacement in the facings are taken to be determined by the relation,

$$\frac{E_f f_1^3}{12\lambda_f} \frac{d^2w}{dx^2} = -M_1 \tag{9}$$

$$\frac{E_f f_2^3}{12\lambda_f} \frac{d^2w}{dx^2} = -M_2 \tag{10}$$

where E_f is the Young's modulus of the facing material, and $\lambda_f = 1 - \nu^2$, where ν is the Poisson ratio of the facing material. Relations (9) and (10), written on the assumption that the curvatures of the two facings are the same, yield

$$M_2 = \frac{f_2^3}{f_1^3} M_1 \tag{11}$$

The shear strain in the core is given by the formula:

$$\gamma_{zx} = \frac{\partial u}{\partial z} + \frac{dw}{dx} \tag{12}$$

On the assumption that the shear strain is constant over the thickness of the core, it follows that u is a linear function of z and this relation can therefore be written

$$\gamma_{zx} = \frac{U_1 - U_2}{c} + \frac{dw}{dx} \tag{13}$$

where U_1 is the component of displacement at the lower surface of facing 1 and U_2 is that at the upper surface of facing 2 (fig. 7). From the relation

$$\tau = G\gamma_{zx} \tag{14}$$

and from (13),

$$\frac{d\tau}{dx} = \frac{G}{c}\left(\frac{dU_1}{dx} - \frac{dU_2}{dx}\right) + \frac{Gd^2w}{dx^2} \tag{15}$$

Now from the stress-strain relation for the facings

$$\frac{dU_1}{dx} = \frac{\lambda_f F_1}{f_1 F_f} - \frac{6\, M_1 \lambda_f}{f_1{}^2\, E_f} \tag{16}$$

and

$$\frac{dU_2}{dx} = \frac{\lambda_f F_2}{f_2 E_f} + \frac{6 M_2 \lambda_f}{f_2{}^2\, E_f} \tag{17}$$

With the substitution of these expressions into (15),

$$\frac{d\tau}{dx} = \frac{G\lambda_f}{cE_f} \left\{ \frac{F_1}{f_1} - \frac{F_2}{f_2} - \frac{6M_1}{f_1{}^2} - \frac{6\, M_2}{f_2{}^2} \right\} + \frac{Gd^2w}{dx^2} \quad ,$$

or, from (8), (9), and (11),

$$\frac{d\tau}{dx} = \frac{G\lambda_f}{cE_f} \left\{ F_1 \frac{(f_1 + f_2)}{f_1 f_2} - \frac{12}{f_1{}^3} \left(c + \frac{f_1 + f_2}{2} \right) M_1 \right\} \tag{18}$$

By differentiation and the substitution of (1)

$$\frac{d^2\tau}{dx^2} = \frac{G\lambda_f}{cE_f} \left\{ \left(\frac{f_1 + f_2}{f_1 f_2} \right) \tau - \frac{12}{f_1{}^3} \left(c + \frac{f_1 + f_2}{2} \right) \frac{dM_1}{dx} \right\} \tag{19}$$

Let

$$S = S_1 + S_2 + c\,\tau \tag{20}$$

This is the shear load on the sandwich, which, according to (6) and (8), is constant. From this expression, together with (7) and (11), a second equation in M_1 and τ is obtained in the form

$$\left(\frac{f_1{}^3 + f_2{}^3}{f_1{}^3} \right) \frac{dM_1}{dx} - S + \left(c + \frac{f_1 + f_2}{2} \right) \tau = 0 \tag{21}$$

By the elimination of $\frac{dM_1}{dx}$ between (19) and (21), it is found that

$$\frac{d^2\tau}{dx^2} - \alpha^2\tau = -\beta \tag{22}$$

with

$$\alpha^2 = \frac{G\lambda_f(f_1 + f_2)I}{c\, f_1 f_2\, E_f\, I_f} \tag{23}$$

$$\beta = \frac{\alpha^2\, I_m\, S}{I\left(c + \frac{f_1 + f_2}{2}\right)} \tag{24}$$

$$I = I_m + I_f \tag{25}$$

$$I_m = \frac{f_1 f_2}{f_1 + f_2}\left(c + \frac{f_1 + f_2}{2}\right)^2 \tag{26}$$

$$I_f = \frac{f_1^3 + f_2^3}{12} \tag{27}$$

An equation in M_1 alone can also be obtained from (19) and (21). It is, however, convenient to retain the term $\frac{d^2\tau}{dx^2}$ in (19) and merely eliminate τ from the right-hand member by substitution from (21). This process, with the substitution of (9) for M_1, leads to the equation:

$$\frac{d^3w}{dx^3} - \frac{cI_m}{GI\left(c + \frac{f_1 + f_2}{2}\right)}\frac{d^2\tau}{dx^2} = -\frac{\lambda_f S}{E_f I} \tag{28}$$

with I and I_m given by (25) and (26). In the notation

$$\phi = \frac{dw}{dx} - \frac{c\, I_m\, \tau}{GI\left(c + \frac{f_1 + f_2}{2}\right)} \tag{29}$$

equation (28) is written

$$\frac{d^2\phi}{dx^2} = -\frac{\lambda_f S}{E_f I} \tag{30}$$

The general solutions of (22) and (30) are, respectively,

$$\tau = A \cosh \alpha x + B \sinh \alpha x + \frac{\beta}{\alpha^2} \tag{31}$$

and

$$\phi = -\frac{\lambda_f S x^2}{2E_f I} + Hx + K \tag{32}$$

The coefficients A, B, H, and K are determined by conditions at the ends of the strip and at load joints or points of support, which are defined as follows.

Clamped End

$$\tau = 0 \tag{33}$$

and

$$\phi = 0 \tag{34}$$

Simply Supported or Free End

$$\frac{d\tau}{dx} = 0 \tag{35}$$

and

$$\frac{d\phi}{dx} = 0 \tag{36}$$

Reference to (29) indicates that (33) and (34) prescribe zero slope in the facings and that (35) and (36) require that the curvature vanish. For the continuation of the solution over load points or points of support, it is prescribed that τ, F_1, M_1, and $\frac{dw}{dx}$ are continuous. It is then found from (18) that $\frac{d\tau}{dx}$ is continuous and from (29) that ϕ and $\frac{d\phi}{dx}$ are continuous.

When the solutions for τ and ϕ have been determined, the deflection is obtained by integration of (29) on the condition that the deflection vanish at a point of support.

The Solutions for τ, ϕ, w and σ_x for Two-point Loading with Overhang[15]

Let a denote the distance from the center of the strip to a load point, b the distance from this load point to the nearer support, and d the length of the overhang, as indicated in figure 3. These various sections of the strip are referred to as spans, and the letters a, b, and d are used as subscripts to associate a moment, force, or stress with a span whose length is the same as the subscript. It is assumed that the strip and the loading are symmetrical about the center of the strip.

In the discussion that follows a separate coordinate x, whose origin is at the left end of the span, is associated with each span.

From (33) and (35) the conditions on τ at the center and free end of the strip are

$$\tau_a(o) = 0 \tag{37}$$

and

$$\frac{d\tau_d(x)}{dx} = 0 \text{ at } x = d \tag{38}$$

At the junctures of the spans the conditions of continuity are

$$\tau_a(a) = \tau_b(o) \tag{39}$$

$$\left.\frac{d\tau_a}{dx}\right|_{x=a} = \left.\frac{d\tau_b}{dx}\right|_{x=b} \tag{40}$$

$$\tau_b(b) = \tau_d(o) \tag{41}$$

$$\left.\frac{d\tau_b}{dx}\right|_{x=b} = \left.\frac{d\tau_d}{dx}\right|_{x=0} \tag{42}$$

With the use of (31) it is found that these various conditions are satisfied by the functions

$$\tau_a(x) = -\frac{S_b I_m}{\left(c + \frac{f_1 + f_2}{2}\right) I}\left[\frac{\sinh \alpha d - \sinh \alpha(b + d)}{\cosh \alpha(a + b + d)}\right]\sinh \alpha x \tag{43}$$

[15] In this section the symbols E and λ are used in place of E_f and λ_f, respectively.

$$\tau_b(x) = \frac{S_b I_m}{\left(c + \frac{f_1 + f_2}{2}\right) I}\left[1 - \left\{\frac{\sinh \alpha d \sinh \alpha(a + x) + \cosh \alpha(b + d - x)\cosh \alpha a}{\cosh \alpha (a + b + d)}\right\}\right] \tag{44}$$

and

$$\tau_d(x) = \frac{S_b I_m}{\left(c + \frac{f_1 + f_2}{2}\right) I}\left[\frac{\cosh \alpha(a + b) - \cosh \alpha a}{\cosh \alpha(a + b + d)}\right]\cosh \alpha(d - x) \tag{45}$$

The conditions imposed on φ are the same as those imposed on τ and are therefore given by (37) to (42) with τ replaced by φ. These conditions applied to (32) yield

$$\varphi_a(x) = \frac{\lambda S_b bx}{EI} \tag{46}$$

$$\varphi_b(x) = \frac{\lambda S_b}{EI}\left\{- \frac{x^2}{2} + bx + ab\right\} \tag{47}$$

$$\varphi_d(x) = \frac{\lambda S_b b}{EI} (a - \frac{b}{2}) \tag{48}$$

According to (29) and to the fact that

$$w_b(b) = 0$$

$$w_b(x) = \int_b^x \varphi_b(x)\, dx + \frac{CI_m}{GI\left(c + \frac{f_1 + f_2}{2}\right)} \int_b^x \tau_b(x)\, dx$$

From (44) and (47)

$$w_b(x) = \frac{\lambda S_b}{EI}\left[- \frac{(x^3 - b^3)}{6} + \frac{b(x^2 - b^2)}{2} + ab(x - b)\right]$$

$$+ \frac{cS_b I_m^2}{G\left(c + \frac{f_1 + f_2}{2}\right)^2 I^2}\left[x - b - \left(\frac{\sinh \alpha d \left\{\cosh \alpha(a + x) - \cosh \alpha(a + b)\right\}}{\alpha \cosh \alpha (a + b + d)} - \frac{\cosh \alpha a \left\{\sinh \alpha(b + d - x) - \sinh \alpha d\right\}}{\alpha \cosh \alpha (a + b + d)}\right)\right] \tag{49}$$

Similarly, since

$$w_a(a) = w_b(0)$$

$$w_a(x) = \int_a^x \phi_a(x)\, dx + \frac{cI_m}{GI\left(c + \frac{f_1 + f_2}{2}\right)} \int_a^x \tau_a(x)\, dx + w_b(0)$$

and from (43), (46), and (49)

$$w_a(x) = \frac{\lambda S_b\, b}{EI} \left\{ \frac{x^2 - a^2}{2} - \frac{b^2}{3} - ab \right\}$$

$$- \frac{cS_b\, I_m^{\,2}}{G\left(c + \frac{f_1 + f_2}{2}\right)^2 I^2} \left[\left\{ \frac{\sinh \alpha d - \sinh \alpha(b + d)}{\alpha \cosh \alpha(a + b + d)} \right\} \cosh \alpha x + b \right.$$

$$\left. + \left\{ \frac{\cosh \alpha a - \cosh \alpha(a + b)}{\alpha \cosh \alpha(a + b + d)} \right\} \sinh \alpha d \right] \quad (50)$$

For the determination of the stresses in the facings, the symbols z_1 and z_2 are used to denote coordinates with origin at the centers of facings 1 and 2, respectively, and with direction the same as that of z in figure 7. Then

$$\sigma_{x1} = \frac{F_1(x)}{f_1} - \frac{z_1 E}{\lambda} \frac{d^2 w}{dx^2} \quad (51)$$

and

$$\sigma_{x2} = \frac{F_2(x)}{f_2} - \frac{z_2 E}{\lambda} \frac{d^2 w}{\;^2} \quad (52)$$

Expressions for $F_1(x)$ and $F_2(x)$ can be obtained from (18) and (8). That for $F_1(x)$ is

$$F_1(x) = \frac{Ec\, f_1 f_2}{G\lambda(f_1 + f_2)} \frac{d\tau}{dx} - \frac{E\, f_1 f_2\left(c + \frac{f_1 + f_2}{2}\right)}{\lambda\,(f_1 + f_2)} \frac{d^2 w}{dx^2} \quad (53)$$

The expression for $\frac{d\tau}{dx}$ obtained from (29) is now substituted into this formula, and the resulting expression is substituted into (51) to obtain

$$\sigma_{x1} = - \frac{1}{f_1\left(c + \frac{f_1 + f_2}{2}\right)} \left[\frac{EI}{\lambda} \frac{d\phi}{dx} - \left\{ 1 - \frac{z_1 f_1 \left(c + \frac{f_1 + f_2}{2}\right)}{I_f} \right\} \frac{EI_f}{\lambda} \frac{d^2 w}{dx^2} \right] \qquad (54)$$

Similarly,

$$\sigma_{x2} = \frac{1}{f_2\left(c + \frac{f_1 + f_2}{2}\right)} \left[\frac{EI}{\lambda} \frac{d\phi}{dx} - \left\{ 1 + \frac{z_2 f_2 \left(c + \frac{f_1 + f_2}{2}\right)}{I_f} \right\} \frac{EI_f}{\lambda} \frac{d^2 w}{dx^2} \right] \qquad (55)$$

The expressions for $\frac{EI}{\lambda} \frac{d\phi}{dx}$ and $\frac{EI_f}{\lambda} \frac{d^2w}{dx^2}$ that are to be used in these formulas are given as follows:

Span a,

$$\frac{EI}{\lambda} \frac{d\phi_a}{dx} = b\, S_b \qquad (56)$$

$$\frac{EI_f}{\lambda} \frac{d^2 w_a}{dx^2} = b\, S_b \left[\frac{I_f}{I} + \frac{I_m}{I} \left\{ \frac{\sinh \alpha(b + d) - \sinh \alpha d}{\alpha b \cosh \alpha(a + b + d)} \right\} \cosh \alpha x \right] \qquad (57)$$

Span b,

$$\frac{EI}{\lambda} \frac{d\phi_b}{dx} = S_b(b - x) \qquad (58)$$

$$\frac{EI_f}{\lambda} \frac{d^2 w_b}{dx^2} = S_b \left[\frac{I_f}{I}(b - x) + \frac{I_m}{I} \left\{ \frac{\sinh \alpha(b + d - x) \cosh \alpha a - \cosh \alpha(a + x) \sinh \alpha d}{\alpha \cosh \alpha(a + b + d)} \right\} \right] \qquad (59)$$

Span d,

$$\frac{EI}{\lambda} \frac{d\phi_d}{dx} = 0 \qquad (60)$$

$$\frac{EI_f}{\lambda} \frac{d^2 w_d}{dx^2} = - \frac{S_b I_m}{I} \left[\frac{\cosh \alpha(a + b) - \cosh \alpha a}{\alpha \cosh \alpha(a + b + d)} \right] \sinh \alpha(d - x) \qquad (61)$$

The formulas of the present section have been derived for application to a strip with two-point loading and with an overhang. These formulas become applicable to a centrally loaded strip with an overhang upon setting $a = 0$. In the event that there is no overhang, the value $d = 0$ is used in the formulas for either two-point or central loading.

Table 1.--Results of individual tests, the computed moduli of rigidity and shear strengths of the cores, the computed tensile and compressive strengths of the facings, and the stresses associated with the measured strains

Specimen number	Span a	Span b	Thickness of upper facing	Slope of load-deflection curve	$\eta \frac{h^2}{4b^2}$	Modulus of rigidity (computed)	Maximum load	Type of failure noted	Bending stress in thin facing at failure (computed)	Shear stress in core at failure (computed)	Computed stress in facing at load associated with largest strain measured: Thin facing	Computed stress in facing at load associated with largest strain measured: Thick facing	Largest strains measured in facings: Thin facing	Largest strains measured in facings: Thick facing	Stresses associated with largest strains: Thin facing	Stresses associated with largest strains: Thick facing
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
	In.	In.	In.	10^{-3} in. per lb.		P.s.i.	Lb.		100 p.s.i.	P.s.i.	100 p.s.i.	100 p.s.i.	10^{-5} in. per in.	10^{-5} in. per in.	100 p.s.i.	100 p.s.i.
Group 1 - Glass-cloth-laminate facings 0.006-inch and 0.0205-inch thick; balsa-wood core 0.251-inch thick																
1T36	4.500	12.500	0.0060	745.00	-0.112	...	3.98	None	157	7.5	157	45.9	500	198	143	76
1B36	4.500	12.500	.0205	790.00	.049	1,260	3.57	...do..	141	6.8	141	41.3	521	174	128	50
1T24	3.000	8.000	.0060	210.00	...	...	6.20	Comp.	156 c	11.7	156	45.7	514	187	147	47
1B24	3.000	8.000	.0205	216.00	.111	1,390	9.95	None	251	18.8	251	73.5	995	319	232	91
1T18	1.500	6.500	.0060	84.50	.051	4,630	6.70	Comp.	137 c	12.7	137	40.1	474	169	135	43
1B18	1.500	6.500	.0205	97.30	.281	820	15.10	None	310 t	28.6	310	90.7	1,273	396	289	113
1T12	1.500	3.500	.0060	20.20	.180	4,690	14.50	Comp.	160 c	27.5	160	46.8	528	197	151	49
1B12	1.500	3.500	.0205	20.20	.180	4,460	24.15	Tension	267 t	45.7	262	76.8	910	313	213	89
1T10	1.500	2.500	.0060	9.45	.161	9,730	29.70	Comp.	234 c	56.2	234	68.5	770	293	220	75
1B10	1.500	2.500	.0205	9.70	.244	6,500	57.00	Tension	449 t	108.0	385	42.7	1,490	469	329	134
1T8	1.000	2.000	.0060	4.28	.207	11,800	40.25	Comp.	254 c	76.2	254	74.3	942	325	267	83
1B8	1.000	2.000	.0205	3.90	-.080	...	64.25	Tension	405 t	121.8	405	118.5	1,510	498	331	142
1T6	.750	1.250	.0060	1.09	-.178	...	52.00	Comp.	205 c	98.4	205	60.0	672	226	192	58
1B6	.750	1.250	.0205	1.15	.024	...	109.25	Tension	431 t	207.2	412	120.6	1,510	480	332	138
Group 2 - Glass-cloth-laminate facings 0.0105-inch and 0.0205-inch thick; balsa-wood core 0.377-inch thick																
2T36	5.000	12.000	.0105	226.20	-.061	...	7.95	Comp.	116	10.1	116	59.4	428	218	121	56
2B36	5.000	12.000	.0205	230.00	.010	1,590	12.00	None	175	15.3	175	89.6	665	341	160	98
2T24	3.000	8.000	.0105	61.20	-.062	...	22.00	Comp.	214 c	28.1	214	109.7	715	449	205	112
2T18	.875	7.125	.0105	26.10	-.045	...	22.15	...do..	192 c	28.2	190	97.1	630	360	180	92
2B18	.875	7.125	.0205	26.60	-.013	...	51.00	Tension	442 t	65.0	442	226.2	1,795	885	381	252
2T12	.875	4.125	.0105	6.44	.026	51,000	35.60	Comp.	178 c	45.4	178	91.2	550	342	157	88
2B12	.875	4.125	.0205	6.72	.085	15,200	96.25	Tension	482 t	122.8	482	247.0	1,812	782	384	224
2B10	.875	3.125	.0205	3.46	.159	14,000	116.00	Shear	440 t	148.0	432	221.2	1,705	840	366	240
2T8	.875	2.125	.0105	1.38	.128	37,700	82.75	Comp.	214 c	105.5	212	108.5	700	407	200	103
2B8	.875	2.125	.0205	1.37	.128	38,000	154.50	Shear	399 t	197.0	399	204.2	1,425	712	317	204
2T6	.875	1.125	.0105	.467	1.856	9,380	188.00	...	256	239.5	256	131.4	845	525	241	129
2B6	.875	1.125	.0205	.467	1.716	10,000	207.00	...	282	263.5	282	144.8	990	528	231	151
Group 3 - Glass-cloth-laminate facings 0.017-inch and 0.0205-inch thick; balsa-wood core 0.504-inch thick																
3T36	5.000	12.000	.0170	100.800	.072	3,820	20.70	Comp.	140	19.8	140	116.0	500	450	143	112
3B36	5.000	12.000	.0205	102.000	.133	2,080	25.80	None	174	24.7	174	144.0	730	512	174	146
3T24	3.000	8.000	.0170	28.500	.131	4,690	40.40	Comp.	182 c	38.6	180	149.0	740	585	212	142
3B24	3.000	8.000	.0205	27.500	.049	12,500	52.50	...do..	236 c	50.2	236	196.0	1,010	705	235	201
3T18	.875	7.125	.0170	12.300	.131	6,000	40.50	Wrinkle	162	38.7	162	134.0	620	540	177	132
3B18	.875	7.125	.0205	12.900	.190	4,090	71.50	Comp.	287 c	68.3	287	238.0	1,260	870	287	248
3T12	.875	4.125	.0170	3.100	.246	9,410	94.50	...do..	219 c	90.4	219	181.0	830	710	237	170
3B12	.875	4.125	.0205	3.120	.245	9,470	137.50	...do..	319 c	131.4	319	265.0	1,320	960	298	272
3T10	.875	3.125	.0170	1.590	.337	11,900	114.50	...do..	201 c	109.5	201	167.0	730	640	209	154
3B10	.875	3.125	.0205	1.700	.531	7,600 g	122.50	...do..	215 c	117.1	213	176.0	870	630	205	180
3T8	.875	2.125	.0170	.672	.590	14,800 g	128.50	...do..	154	122.9	154	128.0	552	470	158	117
3B8	.875	2.125	.0205	.717	.785	11,100 g	149.50	...do..	179	143.0	179	148.0	710	505	170	144
3T6	.875	1.125	.0170	.275	4.307	7,240	250.00	...	158	239.0	158	131.0	530	485	151	120
3B6	.875	1.125	.0205	.265	3.948	7,880	266.00	...	168	254.2	168	140.0	622	481	151	138
Group 4 - Glass-cloth-laminate facings 0.01-inch thick; balsa-wood core 0.750-inch thick																
4T36	5.000	12.000	.0100	79.200	-.150	...	23.75	Comp.	187 c	15.6	187	...	582	630	166	152
4B36	5.000	12.000	.0100	79.200	-.146	...	18.70	...do..	148 c	12.3	148	...	470	462	135	116
4T24	3.000	8.000	.0100	22.500	-.059	...	34.00	...do..	179 c	22.4	179	...	530	590	152	143
4B24	3.000	8.000	.0100	22.000	-.109	...	26.70	...do..	141 c	17.6	141	...	427	450	122	112
4T18	.875	7.125	.0100	9.500	-.028	...	43.30	...do..	203 c	28.5	203	...	620	699	178	166
4B18	.875	7.125	.0100	8.710	-.131	...	48.25	...do..	226 c	31.7	226	...	722	755	206	180
4T12	.875	4.125	.0100	2.367	.050	38,500	39.00	...do..	106 c	25.6	106	...	505	360	145	92
4B12	.875	4.125	.0100	2.417	.080	24,400	61.00	...do..	166 c	40.1	166	...	580	580	166	141
4T10	.875	3.125	.0100	1.225	.120	28,200	141.00	...do..	290 c	92.8	290	...	880	950	251	222
4B10	.875	3.125	.0100	1.233	.152	22,400	125.00	...do..	257 c	82.3	257	...	830	880	237	207
4T8	.875	2.125	.0100	.535	.357	20,490	192.00	...do..	268 c	126.0	268	...	855	910	244	213
4B8	.875	2.125	.0100	.540	.384	19,100	149.50	...do..	209 c	98.4	209	...	660	710	189	170
4T6	.875	1.125	.0100	.215	3.514	7,440	266.50	...	197	175.3	197	...	625	650	179	157
4B6	.875	1.125	.0100	[illegible]	3.402	7,670	199.00	...	147	131.0	140	...	485	438	139	110
Group 5 - Aluminum-laminate facings 0.012-inch and 0.0305-inch thick; balsa-wood core 0.757-inch thick																
5T36	5.000	12.000	.0305	12.830	-.017	...	90.50	None	582 c	58.2	578	227.0	910	240	521	248
5B36	5.000	12.000	.0120	13.000	-.043	...	93.00	...do..	598 c	59.8	598	235.0	1,800	286	...	288
5T24	3.000	8.000	.0305	4.100	.291	11,300	147.00	...do..	631 c	94.5	604	238.0	2,490	365	...	348
5B24	3.000	8.000	.0120	3.950	.182	18,100	133.00	Wrinkle	570 c	85.5	570	224.0	1,460	262	...	272
5T18	.875	7.125	.0305	1.810	.265	15,800	171.00	None	652 c	109.8	648	255.0	2,420	305	...	304
5B18	.875	7.125	.0120	1.780	.257	17,600 g	127.00	Wrinkle	483 c	81.6	483	190.0	770	205	464	217
5T12	.875	4.125	.0305	.570	.975	12,700 g	259.00	Shear	573 c	166.5 s	573	225.0	1,310	247	...	254
5B12	.875	4.125	.0120	.645	.618	20,100 g	199.00	...do..	440	128.0 s	440	173.0	580	180	429	192
5T10	.875	3.125	.0305	.315	1.440	15,000 g	321.00	...do..	537	216.3 s	537	211.0	682	420	514	376
5B10	.875	3.125	.0120	.345	1.764	12,300 g	290.00	Wrinkle	486	186.4 s	486	191.0	700	207	452	218
5T8	.875	2.125	.0305	.169	3.508	14,100	235.00	Shear	268	151.1 s	268	106.0	236	106	248	112
5B8	.875	2.125	.0120	.174	3.435	13,600	218.00	...do..	248	140.1 s	248	98.0	220	95	230	100

Table 1.--Results of individual tests, the computed moduli of rigidity and shear strengths of the cores, the computed tensile and compressive strengths of the facings, and the stresses associated with the measured strains (continued)

Specimen number	Span a	Span b	Thickness of upper facing	Slope of load-deflection curve	$\eta \frac{h^2}{4b^2}$	Modulus of rigidity (computed)	Maximum load	Type of failure noted	Bending stress in thin facing at failure (computed)	Shear stress in core at failure (computed)	Computed stress in facing at load associated with largest strain measured: Thin facing	Computed stress in facing at load associated with largest strain measured: Thick facing	Largest strains measured in facings: Thin facing	Largest strains measured in facings: Thick facing	Stresses associated with largest strains: Thin facing	Stresses associated with largest strains: Thick facing
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
	In.	In.	In.	10^{-3} in. per lb.		P.s.i.	Lb.		100 p.s.i.	P.s.i.	100 p.s.i.	100 p.s.i.	10^{-5} in. per in.	10^{-5} in. per in.	100 p.s.i.	100 p.s.i.
Group 6 - Aluminum facings 0.020-inch and 0.031-inch thick; balsa-wood core 0.753-inch thick																
6T36	5.000	12.000	0.0200	10.000	0.174	11,700	135.00	None	522	86.8	522	337	1,440	395		397
6B36	5.000	12.000	.0310	10.000	.157	12,900	129.00	...do...	498	82.9	498	322	1,742	375		354
6T24	3.000	8.000	.0200	2.970	.327	14,000	199.00	...do...	511	128.0	511	330	1,290	387	524	388
6B24	3.000	8.000	.0310	2.950	.300	15,300	195.00	...do...	501	125.3	497	321	2,590	425		380
6T18	.875	7.125	.0200	1.440	.471	12,400 g	236.00	Shear	540	151.3 s	540	349	1,800	425		426
6B18	.875	7.125	.0310	1.400	.405	14,300 g	208.00	...do...	476	133.7 s	476	307	1,040	325		320
6T12	.875	4.125	.0200	.500	1.596	10,800 g	255.00	...do...	338	164.0 s	338	218	350	225	339	237
6B12	.875	4.125	.0310	.465	1.336	12,900 g	297.00	...do...	394	191.0 s	391	252	485	257	479	262
6T10	.875	3.125	.0200	.323	2.952	10,200 g	272.00	...do...	273	174.6 s	273	176	276	178	280	188
6B10	.875	3.125	.0310	.288	2.414	12,500 g	282.00	...do...	283	181.2 s	283	183	300	185	307	195
6T8	.875	2.125	.0200	.187	6.449	10,100	237.00	...do...	162	152.2 s	162	104	158	104	164	109
6B8	.875	2.125	.0310	.177	6.029	10,800	254.00	...do...	173	163.2 s	173	112	170	110	180	118
Group 7 - Aluminum facings 0.012-inch thick; balsa-wood core 0.744-inch thick																
7T36	5.000	12.000	.0120	21.000	.097	10,400	75.00	None	496	49.6	496		950	800	489	518
7B36	5.000	12.000	.0120	20.750	.079	12,900	74.00	...do...	493	49.2	493		960	565	490	511
7T24	3.000	8.000	.0120	5.850	.122	18,700	126.00	Wrinkle	557 c	83.6	557		1,450	1,170		
7B24	3.000	8.000	.0120	5.900	.152	15,100	127.00	...do...	558 c	83.8	558		2,100	1,625		
7T18	.875	7.125	.0120	2.750	.264	10,900	156.00	...do...	612 c	103.1	589		2,340	2,400		
7B18	.875	7.125	.0120	2.650	.204	14,200	151.00	None	593 c	99.8	590		2,280	2,540		
7T12	.875	4.125	.0120	.780	.714	12,100 g	213.00	Shear	484	140.8 s	484		835	550	474	510
7B12	.875	4.125	.0120	.740	.608	14,200 g	262.00	Wrinkle	593 c	173.2 s	593		1,960	2,330		
7T10	.875	3.125	.0120	.490	1.444	10,400 g	190.00	...do...	328	126.0 s	328		332	312	327	319
7B10	.875	3.125	.0120	.465	1.343	11,200 g	226.00	Shear	389	147.3 s	389		470	367	398	370
7T8	.875	2.125	.0120	.230	2.687	12,000 g	293.00	Wrinkle	345	193.8 s	343		357	323	344	340
7B8	.875	2.125	.0120	.245	3.026	10,700	291.00	Shear	341	192.4 s	340		348	320	337	327
7T6	.875	1.125	.0120	.167	21.279	5,400	360.00		223	238.0	223		207	202	216	214
7B6	.875	1.125	.0120	.148	18.215	6,400	411.00		255	271.8	250		245	231	253	240
Group 8 - Aluminum facings 0.012-inch and 0.019-inch thick; balsa-wood core 0.505-inch thick																
8T36	5.000	12.000	.0190	36.000	.033	25,200	51.00	None	490	49.0	490	309	1,061	735		448
8B36	5.000	12.000	.0120	35.500	.000		51.00	...do...	490	49.0	490	309	1,310	342		547
8T24	3.000	8.000	.0190	9.620	.011	16,400	89.00	...do...	570	85.6	570	360	2,630	462		394
8B24	3.000	8.000	.0120	9.880	.042	44,200	84.00	Wrinkle	537 c	80.5	537	339	1,360	373		377
8T18	.875	7.125	.0190	4.250	.088	27,000	115.00	Tension	656 t	110.7	616	489	2,620	690		449
8B18	.875	7.125	.0120	4.620	.209	11,300	110.00	Wrinkle	624 c	105.2	599	378	2,300	452		452
8T12	.875	4.125	.0190	1.180	.422	16,800 g										
8B12	.875	4.125	.0120	1.230	.510	13,900 g	189.00	Shear	625 c	181.8 s	625	395	2,260	490		483
8T10	.875	3.125	.0190	.685	.867	14,200 g	199.00	...do...	497	191.0 s	497	314	500	305	492	305
8B10	.875	3.125	.0120	.680	.867	14,200 g	226.00	...do...	566 c	217.3 s	566	358	1,440	390		394
8T8	.875	2.125	.0190	.372	2.288	11,500 g	196.00	...do...	335	189.0 s	335	212	326	205	330	214
8B8	.875	2.125	.0120	.358	2.125	12,400 g	246.00	...do...	419	236.7 s	419	265	525	265	416	272
8T6	.875	1.125	.0190	.164	9.954	9,400	316.00		284	303.5	284	180	270	176	276	185
8B6	.875	1.125	.0120	.228	15.199	6,100	219.00		197	210.2	197	125	195	118	204	124
Group 8A - Aluminum facings 0.012-inch and 0.019-inch thick; balsa-wood core 0.501-inch thick																
8AT36	5.000	12.000	.0120	35.000	-.003		50.00	None	485	48.4	485	306.0	905	325	483	330
8AB36	5.000	12.000	.0190	35.000	-.040		53.00	...do...	514	51.3	514	325.0	695	335	515	328
8AT24	3.000	8.000	.0120	10.250	.138	13,400	88.00	...do...	569	85.2	569	359.0	1,880	440		440
8AB24	3.000	8.000	.0190	10.000	.066	28,100	87.00	...do...	562	84.2	562	355.0	1,790	400		368
8AT18	.875	7.125	.0120	4.580	.210	11,300	116.00	Wrinkle	671 c	112.8	630	398.0	2,460	530		509
8AB18	.875	7.125	.0190	4.580	.197	12,000	113.00	Tension	630 t	109.4	610	385.0	2,660	465		396
8AT12	.875	4.125	.0120	1.200	.377	18,400	187.00	Wrinkle	623 c	181.1 s	623	394.0	2,460	510		500
8AB12	.875	4.125	.0190	1.200	.358	19,300	204.00	Shear	679	197.3 s	605	382.0	1,970	1,760		
8AT10	.875	3.125	.0120	.720	.959	12,800 g										
8AB10	.875	3.125	.0190	.715	.946	12,900 g	171.00	Shear	432	165.7 s	432	273.0	417	267	418	273
8AT8	.875	2.125	.0120	.365	2.119	12,300 g	238.00	...do...	408	230.0 s	408	258.0	480	257	401	264
8AB8	.875	2.125	.0190	.339	1.809	14,400 g	208.00	...do...	358	202.0 s	258	226.0	450	295	450	297
8AT6	.875	1.125	.0120	.198	12.721	7,300	276.00		250	266.8	250	158.0	240	1,480		
8AB6	.875	1.125	.0190	.197	12.601	7,400	268.00		244	260.0	244	154.0	223	1,540	232	164
Group 9 - Aluminum facings 0.012-inch and 0.031-inch thick; cellular cellulose-acetate core 0.502-inch thick																
9T36	5.000	12.000	.0310	31.880	.200	4,600	53.00	None	507 c	50.6	507	196.0	1,112	250		258
9B36	5.000	12.000	.0120	32.200	.283	3,300	44.00	Wrinkle	418 c	41.8	418	162.0	575	177	428	187
9T24	3.000	8.000	.0310	9.500	.435	4,800 g	89.00	Shear	565 c	84.7 s	565	218.0	2,550	332		326
9T18	.875	7.125	.0310	4.750	.594	4,500 g	104.00	...do...	594 c	99.8 s	594	230.0	2,500	290		292
9B18	.875	7.125	.0120	4.880	.622	4,300 g										
9T12	.875	4.125	.0310	1.540	1.597	5,000 g	111.00	Shear	365	106.0 s	365	141.0	355	147	358	155
9B10	.875	3.125	.0120	.925	2.598	5,300 g	96.00	...do...	238	91.2 s	238	92.2	228	99	235	103
9T8	.875	2.125	.0310	.622	6.941	4,200	120.00	...do...	204	115.0 s	204	79.0	195	80	205	85
9B8	.875	2.125	.0120	.625	6.934	4,200	116.00	...do...	196	110.3 s	196	75.8	190	85	203	89
9T6	.875	1.125	.0310	.376	35.051	3,000	130.00		116	124.1	116	45.0	107	45	112	46
9B6	.875	1.125	.0120	.464	45,000	2,300	122.00		110	116.9	110	42.4	125	58	132	59

Table 1.--Results of individual tests, the computed moduli of rigidity and shear strengths of the cores, the computed tensile and compressive strengths of the facings, and the stresses associated with the measured strains (continued)

Specimen number	Span a	Span b	Thickness of upper facing	Slope of load-deflection curve	$\eta \frac{h^2}{4b^2}$	Modulus of rigidity (computed)	Maximum load	Type of failure noted	Bending stress in thin facing at failure (computed)	Shear stress in core at failure (computed)	Computed stress in facing at load associated with largest strain measured: Thin facing	Computed stress in facing at load associated with largest strain measured: Thick facing	Largest strains measured in facings: Thin facing	Largest strains measured in facings: Thick facing	Stresses associated with largest strains: Thin facing	Stresses associated with largest strains: Thick facing
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
	In.	In.	In.	10^{-3} in. per lb.		P.s.i.	Lb.		100 p.s.i.	P.s.i.	100 p.s.i.	100 p.s.i.	10^{-5} in. per in.	10^{-5} in. per in.	100 p.s.i.	100 p.s.i.
Group 10 - Aluminum facings 0.012-inch and 0.030-inch thick; paper honeycomb core 0.746-inch thick																
10T36	5.000	12.000	0.030	13.750	-0.006		88.00	None	574	57.4	574	230.0	1,590	267		273
10B36	5.000	12.000	.012	14.000	.049	29,100	83.00	...do..	541	54.1	541	215.0	1,115	232	507	239
10T24	3.000	8.000	.030	4.080	.172	18,700	128.00	...do..	556	83.5	556	222.0	1,190	245		253
10B24	[illegible]	8.000	.012	4.080	.161	19,900	144.00	Wrinkle	628 c	94.2	628	251.0	2,125	298		304
10T18	.875	7.125	.030	1.840	.246	16,600	164.00	None	635	106.9	635	254.0	2,480	310		307
10B18	.875	7.125	.012	1.930	.276	14,600	154.00	Wrinkle	598 c	100.7	598	239.0	1,760	280		284
10T12	.875	4.125	.030	.560	.797	15,100 g	280.00	Shear	628	182.5 s	628	251.0	2,180	292		301
10B12	.875	4.125	.012	.575	.865	13,900 g	264.00	Wrinkle	592 c	172.1 s	592	237.0	1,630	280		284
10T10	.875	3.125	.030	.342	1.578	13,300 g	263.00	Shear	446	171.3 s	446	178.0	420	180	420	190
10B10	.875	3.125	.012	.350	1.586	13,100 g	322.00	...do..	548	210.2 s	548	219.0	1,190	245	514	253
10T8	.875	2.125	.030	.187	3.620	12,600	431.00	...do..	498	281.0 s	498	199.0	490	192	482	202
10B8	.875	2.125	.012	.197	4.058	11,300	334.00	...do..	374	217.8 s	374	150.0	427	161	380	171
Group 11 - Aluminum facings 0.032-inch thick; balsa-wood core 0.506-inch thick																
11T32	5.000	10.000	.0320	10.170	.328	7,800	168.00	None	488	156.0	488		898	500	481	490
11B32	5.000	10.000	.0320	10.330	.348	7,300	159.00	Wrinkle	462 c	148.0	462		885	539	480	509
11T24	1.000	10.000	.0320	4.940	.220	11,500	179.00	...do..	525 c	167.0	525		1,450	1,240		
11B24	1.000	10.000	.0320	4.880	.192	13,100	173.00	...do..	503 c	161.0	503		1,235	855	519	519
11T16	.875	6.125	.0320	1.450	.483	14,000 g	231.00	Shear	411	215.0 s	411		504	417	409	419
11B16	.875	6.125	.0320	1.440	.466	14,400 g	216.00	...do..	384	201.0 s	384		475	390	400	391
11T12	.875	4.125	.0320	.694	1.345	11,100 g	208.00	...do..	249	193.0 s	249		230	245	238	253
11B12	.875	4.125	.0320	.656	1.166	12,700 g	213.00	...do..	255	198.0 s	255		253	242	261	250
11T8	.875	2.125	.0320	.230	4.759	11,600	262.00	...do..	161	243.0 s	161		161	155	170	164
11B8	.875	2.125	.0320	.258	5.731	9,600	240.00	...do..	148	225.0 s	148		147	142	155	151
Group 12 - Aluminum facings 0.032-inch thick; balsa-wood core 0.390-inch thick																
12T32	5.000	10.000	.0320	17.000	.213	9,000	113.00	None	418	129.0	418		532	630	417	513
12B32	5.000	10.000	.0320	16.400	.193	9,900	117.00	...do..	433	132.0	433		535	618	418	512
12B24	1.000	10.000	.0320	7.800	.160	12,000	135.00	Wrinkle	500 c	154.0	500		1,069	1,360	503	
12T16	.875	6.125	.0320	2.400	.507	10,100 g	188.00	Shear	426	214.0 s	426					
12B16	.875	6.125	.0320	2.180	.322	15,800	196.00	...do..	446	223.0 s	444		592	692	431	515
12T12	.875	4.125	.0320	1.040	.997	11,200 g	177.00	...do..	271	202.0 s	271		280	295	284	301
12B12	.875	4.125	.0320	.900	.697	16,100 g	225.00	...do..	344	257.0 s	344		360	370	345	373
12T8	.875	2.125	.0320	.285	3.124	13,600	220.00	...do..	173	253.0 s	173		175	175	185	185
12B8	.875	2.125	.0320	.292	3.215	13,100	220.00	...do..	173	254.0 s	173		173	176	184	186
Group 13 - Aluminum facings 0.020-inch thick; balsa-wood core 0.257-inch thick																
13T32	5.000	10.000	.0200	58.670	.114	7,000	39.50	None	356	68.8	356		405	364	370	368
13B32	5.000	10.000	.0200	59.330	.141	5,600	39.50	...do..	356	68.8	356		405	375	370	378
13T24	1.000	10.000	.0200	29.000	.154	5,200	53.00	...do..	478	92.4	478		1,298	712		515
13B24	1.000	10.000	.0200	28.500	.145	5,500	53.00	...do..	478	92.4	478		1,070	822	501	518
13T16	.875	6.125	.0200	7.750	.262	8,100	90.80	Wrinkle	501 c	157.0	501		1,120	820	508	518
13B16	.875	6.125	.0200	7.500	.201	10,500	94.00	None	515 c	163.8	519		1,610	212		
13T12	.875	4.125	.0200	2.980	.440	10,600 g	114.50	Shear	426	198.8 s	426		650	465	442	426
13B12	.875	4.125	.0200	2.950	.416	11,200 g	116.00	...do..	431	202.1 s	451		690	470	449	466
13T8	.875	2.125	.0200	.775	1.591	11,000 g	114.50	...do..	220	198.8 s	220		225	220	234	230
13B8	.875	2.125	.0200	.758	1.485	11,800 g	133.50	...do..	256	232.8 s	256		270	264	274	272
Group 14 - Aluminum facings 0.012-inch thick; balsa-wood core 0.260-inch thick																
14B32	5.000	10.000	.0120	93.600	-.092		24.80	None	380	45.6	380		396	350	365	354
14T24	1.000	10.000	.0120	45.500	.019	26,500	31.50	...do..	483	57.9	450		440	620	385	513
14B24	1.000	10.000	.0120	45.500	.019	26,500	33.80	Wrinkle	517 c	62.0	517		610	912	435	521
14T16	.875	6.125	.0120	11.700	.040	32,600	61.20	...do..	575 c	112.7	575		1,549	1,735		
14B16	.875	6.125	.0120	11.800	.062	21,300	62.00	None	587 c	115.0	587		1,975	2,535		
14T12	.875	4.125	.0120	4.450	.136	21,300	94.00	Wrinkle	594 c	172.8	594		1,540	1,605		
14B12	.875	4.125	.0120	4.450	.136	21,200	98.00	...do..	617 c	180.2	617		2,180	2,300		
14T8	.875	2.125	.0120	1.010	.591	18,500 g	119.50	Shear	389	219.8 s	389		424	345	378	348
14B8	.875	2.125	.0120	1.120	.917	11,900 g	84.50	Shear	275	155.3 s	275		250	250	257	259
Group 15 - Aluminum facings 0.032-inch thick; cellular cellulose-acetate core 0.496-inch thick																
15T32	5.000	10.000	.0320	11.000	.419	5,900	120.00	Wrinkle	354 c	113.0	354		357	372	344	391
15B32	5.000	10.000	.0320	11.000	.398	6,200	100.00	...do..	297 c	95.0	297		298	315	300	320
15T24	1.000	10.000	.0320	5.280	.274	9,000	127.00	...do..	376 c	120.0	376		405	428	369	428
15B24	1.000	10.000	.0320	5.030	.195	12,700	128.00	...do..	379 c	121.0	379		415	307	374	310
15T16	.875	6.125	.0320	1.800	.847	7,800 g	150.00	Shear	272	142.0 s	272		372	291	352	300
15B16	.875	6.125	.0320	1,850	.911	7,200 g	154.00	...do..	279	146.0 s	279		274	295	282	299
15T12	.875	4.125	.0320	.892	2.016	7,200 g	155.00	...do..	189	147.0 s	189		185	194	190	205
15B12	.875	4.125	.0320	.875	1.940	7,400 g	148.00	...do..	181	140.0 s	181		179	187	187	197
15T8	.875	2.125	.0320	.359	8.564	6,400	186.00	...do..	117	176.0 s	117		103	120	110	127
15B8	.875	2.125	.0320	.388	7.919	6,900	179.00	...do..	113	170.0 s	113		102	115	100	122

Table 1.--Results of individual tests, the computed moduli of rigidity and shear strengths of the cores, the computed tensile and compressive strengths of the facings, and the stresses associated with the measured strains (continued)

Specimen number	Span a	Span b	Thickness of upper facing	Slope of load-deflection curve	$\frac{\pi^2 h^2}{4b^2}$	Modulus of rigidity (computed)	Maximum load	Type of failure noted	Bending stress in thin facing at failure (computed)	Shear stress in core at failure (computed)	Computed stress in facing at load associated with largest strain measured: Thin facing	Computed stress in facing at load associated with largest strain measured: Thick facing	Largest strains measured in facings: Thin facing	Largest strains measured in facings: Thick facing	Stresses associated with largest strains: Thin facing	Stresses associated with largest strains: Thick facing
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
	In.	In.	In.	10^{-5} in. per lb.		P.s.i.	Lb.		100 p.s.i.	P.s.i.	100 p.s.i.	100 p.s.i.	10^{-5} in. per in.	10^{-5} in. per in.	100 p.s.i.	100 p.s.i.
Group 16 - Aluminum facings 0.032-inch thick; cellular cellulose-acetate core 0.370-inch thick																
16T32	5.000	10.000	0.0320	20.000	0.526	3,400 g	99.50	Wrinkle	371 c	118.8	371	....	455	390	392	392
16B32	5.000	10.000	.0320	21.800	.831	2,200 g	72.00	...do...	280 c	89.6	280	....	290	291	290	298
16T24	1.000	10.000	.0320	10.000	.423	4,300 g	96.30	...do...	374 c	119.9	374	....	488	392	404	395
16B24	1.000	10.000	.0320	10.700	.530	3,400 g	83.00	...do...	323 c	103.2	318	....	339	327	330	331
16T16	.875	6.125	.0320	3.580	1.173	4,100 g	114.00	Shear	273	141.9 s	273	....	286	279	289	283
16B16	.875	6.125	.0320	3.650	1.257	3,800 g	106.50	...do...	253	132.5 s	253	....	268	276	272	282
16T12	.875	4.125	.0320	1.700	2.337	4,500 g	125.00	...do...	200	155.6 s	200	....	215	208	225	218
16B12	.875	4.125	.0320	2.300	3.852	2,800	76.50	...do...	124	94.6 s	124	....	130	138	139	146
16T8	.875	2.125	.0320	.666	9.340	4,300	138.00	...do...	114	171.8 s	114	....	120	120	127	127
16B8	.875	2.125	.0320	.860	12.805	3,100	92.50	...do...	76	115.1 s	76	....	81	84	86	89
Group 17 - Aluminum facings 0.020-inch thick; cellular cellulose-acetate core 0.244-inch thick																
17B32	5.000	10.000	.0200	66.880	.209	3,600	34.00	None	323	64.6	323	....	350	365	339	369
17B16	.875	6.125	.0200	9.030	.341	5,800	69.00	Wrinkle	402 c	131.1	400	....	460	507	394	496
17T12	.875	4.125	.0200	3.870	.847	5,200 g	63.00	Shear	247	119.7 s	247	....	260	265	266	272
17B12	.875	4.125	.0200	3.600	.668	6,600 g	85.80	...do...	336	163.0 s	336	....	355	367	341	370
17T8	.875	2.125	.0200	.967	2.082	7,900 g	108.80	...do...	219	206.9 s	219	....	231	231	240	243
17B8	.875	2.125	.0200	1.016	2.318	7,100 g	106.00	...do...	214	201.5 s	214	....	229	231	237	243
Group 18 - Aluminum facings 0.012-inch thick; cellular cellulose-acetate core 0.247-inch thick																
18T32	5.000	10.000	.0120	115.000	.098	4,800	27.00	None	435 c	52.1	....	....	....	....	....	....
18B32	5.000	10.000	.0120	110.000	.022	21,400	14.00	Glue	226	27.0	226	....	215	206	218	217
18T24	1.000	10.000	.0120	53.500	.153	3,100	27.10	Wrinkle	437 c	52.3	437	....	597	443	432	442
18T16	.875	6.125	.0120	17.000	.410	3,000 g	34.30	Shear	338 c	66.2 s	338	....	340	371	332	374
18B16	.875	6.125	.0120	15.800	.324	3,800	27.40	...do...	270	52.9 s	270	....	275	260	282	266
18T12	.875	4.125	.0120	7.200	.947	2,900 g	42.00	...do...	279	81.1 s	279	....	278	270	283	276
18B12	.875	4.125	.0120	6.400	.719	3,800 g	42.50	...do...	282	82.1 s	282	....	318	269	316	275
18T8	.875	2.125	.0120	1.820	2.597	4,000 g	77.30	...do...	265	149.2 s	265	....	255	244	262	252
Group 19 - Aluminum facings 0.032-inch thick; paper honeycomb core 0.755-inch thick																
19T32	3.000	12.000	.0320	5.920	.402	6,600 g	180.00	Wrinkle	428 c	114.0	422	....	535	630	419	513
19B32	3.000	12.000	.0320	5.920	.381	7,000	178.00	...do...	423 c	113.0	423	....	543	615	421	512
19T24	1.000	10.000	.0320	2.780	.504	7,600 g	189.00	...do...	375 c	120.0	375	....	401	424	369	425
19B24	1.000	10.000	.0320	2.810	.528	7,200 g	191.00	...do...	379 c	121.0	376	....	420	405	376	409
19T16	.875	6.125	.0320	.970	1.298	7,900 g	225.00	Shear	274	143.0 s	274	....	265	283	272	291
19B16	.875	6.125	.0320	.975	1.282	7,900 g	232.00	...do...	282	147.0 s	282	....	280	295	286	301
19T12	.875	4.125	.0320	.460	2.398	8,700 g	242.00	...do...	198	154.0 s	198	....	189	203	200	211
19B12	.875	4.125	.0320	.480	2.686	8,400 g	246.00	...do...	203	156.0 s	203	....	207	198	218	206
19T8	.875	2.125	.0320	.219	12.422	6,800	264.00	...do...	111	168.0 s	111	....	104	108	110	114
19B8	.875	2.125	.0320	.232	13.279	6,400	255.00	...do...	108	163.0 s	108	....	100	110	117	116
Group 20 - Aluminum facings 0.032-inch thick; paper honeycomb core 0.634-inch thick																
20T32	3.000	12.000	.0320	8.330	.364	6,100	152.00	Wrinkle	427 c	114.0	427	....	592	784	431	517
20B32	3.000	12.000	.0320	8.170	.358	6,200	162.00	...do...	456 c	122.0	456	....	858	1,020	477	525
20T24	1.000	10.000	.0320	3.550	.354	9,000	190.00	Shear	446 c	143.0	446	....	677	900	447	521
20B24	1.000	10.000	.0320	3.600	.387	8,200	195.00	...do...	458 c	146.0	458	....	792	898	468	521
20T16	.875	6.125	.0320	1.170	.895	9,400 g	218.00	...do...	314	164.0 s	314	....	324	344	322	348
20B16	.875	6.125	.0320	1.180	.962	8,800 g	220.00	...do...	315	165.0 s	314	....	314	327	311	332
20T12	.875	4.125	.0320	.565	1.970	9,500 g	227.00	...do...	220	170.0 s	218	....	215	225	224	233
20B12	.875	4.125	.0320	.580	2.159	8,600 g	247.00	...do...	239	185.0 s	238	....	190	217	200	225
20T8	.875	2.125	.0320	.211	7.840	9,000	270.00	...do...	134	202.0 s	134	....	130	138	137	146
20B8	.875	2.125	.0320	.266	10.535	6,700	268.00	...do...	134	201.0 s	134	....	130	128	137	135
Group 21 - Glass-cloth-laminate facings 0.024-inch thick; balsa-wood core 0.498-inch thick																
21T32	5.000	10.000	.0240	51.500	.026	18,500	53.00	None	212	50.8	212	....	705	920	202	217
21B32	5.000	10.000	.0240	49.500	-.051	....	52.80	...do...	211	50.5	211	....	742	880	213	207
21T24	1.000	10.000	.0240	25.500	.150	3,300	52.00	Comp.	208 c	49.8	208	....	788	892	226	209
21B24	1.000	10.000	.0240	25.500	.172	2,900	50.30	...do...	201 c	48.2	201	....	782	830	224	195
21T16	.875	6.125	.0240	6.620	.178	7,400	92.50	...do...	226 c	88.6	226	....	860	960	245	225
21B16	.875	6.125	.0240	6.880	.218	6,000	83.80	...do...	205 c	80.2	205	....	775	890	222	209
21T12	.875	4.125	.0240	2.320	.206	14,100	154.80	...do...	255 c	148.3	249	....	790	1,030	226	239
21B12	.875	4.125	.0240	2.400	.224	12,800	164.50	Shear	271 c	157.5	271	....	915	1,110	260	257
21T8	.875	2.125	.0240	.600	.951	11,200 g	201.00	...do...	171	192.6 s	170	....	660	725	189	173
21B8	.875	2.125	.0240	.710	1.662	6,500 g	186.50	...do...	158	178.7 s	158	....	605	652	174	157

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Table 1.--Results of individual tests, the computed moduli of rigidity and shear strengths of the cores, the computed tensile and compressive strengths of the facings, and the stresses associated with the measured strains (continued)

Specimen number	Span a	Span b	Thickness of upper facing	Slope of load-deflection curve	$\eta \frac{h^2}{4b^2}$	Modulus of rigidity (computed)	Maximum load	Type of failure noted	Bending stress in thin facing at failure (computed)	Shear stress in core at failure (computed)	Computed stress in facing at load associated with largest strain measured: Thin facing	Computed stress in facing at load associated with largest strain measured: Thick facing	Largest strains measured in facings: Thin facing	Largest strains measured in facings: Thick facing	Stresses associated with largest strains: Thin facing	Stresses associated with largest strains: Thick facing
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
	In.	In.	In.	10^{-3} in. per lb.		P.s.i.	Lb.		100 p.s.i.	P.s.i.	100 p.s.i.	100 p.s.i.	10^{-5} in. per in.	10^{-5} in. per in.	100 p.s.i.	100 p.s.i.
Group 22 - Glass-cloth laminate facings 0.024-inch thick; balsa-wood core 0.374-inch thick																
22T32	5.000	10.000	0.0240	91.200	0.188	2,000	28.30	None	148	35.6	148	...	610	691	175	165
22B32	5.000	10.000	.0240	92.500	.225	1,600	28.10	...do...	147	35.3	147	...	610	652	175	157
22T24	1.000	10.000	.0240	44.000	.140	2,600	46.20	Comp.	242 c	58.0	242	...	942	1,120	267	260
22B24	1.000	10.000	.0240	44.200	.143	2,600	42.60	...do...	223 c	53.7	223	...	915	980	260	229
22T16	.875	6.125	.0240	11.700	.225	4,300	74.30	...do...	239 c	93.6	239	...	938	1,045	266	239
22B16	.875	6.125	.0240	11.400	.177	5,500	68.00	Wrinkle	218 c	85.5	218	...	881	941	251	220
22T12	.875	4.125	.0240	4.120	.236	9,000	140.50	Comp.	303 c	176.7	284	...	1,105	1,272	308	289
22B12	.875	4.125	.0240	4.150	.294	7,200	123.50	...do...	276 c	156.1	261	...	1,030	1,134	289	264
22T8	.875	2.125	.0240	1.050	.973	8,100 g	157.50	Shear	153	172.8 s	153	...	580	660	166	159
22B8	.875	2.125	.0240	1.030	1.058	7,600 g	124.50	Comp.	139	156.5 s	139	...	586	562	167	137
Group 23 - Glass-cloth laminate facings 0.024-inch thick; balsa-wood core 0.247-inch thick																
23T32	5.000	10.000	.0240	208.000	.262	900	13.00	Wrinkle	99	23.9	99	...	438	445	125	111
23B32	5.000	10.000	.0240	210.000	.351	700	13.00	None	100	24.0	100	...	429	463	123	116
23T24	1.000	10.000	.0240	97.000	.186	1,300	21.90	Comp.	168 c	40.4	168	...	730	800	209	189
23B24	1.000	10.000	.0240	95.000	.171	1,400	22.20	Wrinkle	171 c	41.0	171	...	693	772	198	183
23T16	.875	6.125	.0240	24.800	.222	2,800	46.50	Comp.	219 c	85.8	219	...	940	1,030	267	239
23T12	.875	4.125	.0240	8.880	.305	4,600	69.50	Wrinkle	221 c	128.1	221	...	891	985	254	230
23B12	.875	4.125	.0240	8.800	.257	5,400	41.00	...do...	130 c	75.6	127	...	540	538	155	132
23T8	.875	2.125	.0240	2.070	.729	6,900 g	134.00	Shear	220 c	247.3 s	217	...	...	...	...	...
23B8	.875	2.125	.0240	1.980	.522	9,700 g	136.50	...do...	220 c	251.0 s	222	...	910	990	259	231
Group 24 - Glass-cloth-laminate facings 0.024-inch thick; cellular cellulose-acetate core 0.498-inch thick																
24T32	5.000	10.000	.0240	53.000	.211	2,400	46.00	Wrinkle	184	44.1	184	...	692	739	198	176
24B32	5.000	10.000	.0240	48.500	-.117	...	53.50	Comp.	215 c	51.2	213	...	737	833	211	196
24T24	1.000	10.000	.0240	25.000	.116	4,300	34.80	Wrinkle	139 c	33.3	139	...	518	555	148	136
24B24	1.000	10.000	.0240	25.600	.151	3,300	60.80	Comp.	243 c	58.2	243	...	922	1,071	262	249
24T16	.875	6.125	.0240	6.760	.203	6,500	60.00	Wrinkle	147 c	67.4	147	...	540	575	154	140
24B16	.875	6.125	.0240	6.800	.171	7,500	65.80	Shear	161 c	63.0	161	...	587	672	168	162
24T12	.875	4.125	.0240	2.420	.233	12,400	124.80	Comp.	206 c	119.6	206	...	...	...	...	...
24T8	.875	2.125	.0240	.695	1.504	6,700 g	135.50	...do...	115	129.8 s	115	...	369	452	106	112
24B8	.875	2.125	.0240	.690	15.020	7,200 g	157.00	...do...	133	150.1 s	131	...	480	520	137	128
Group 25 - Glass-cloth-laminate facings 0.024-inch thick; cellular cellulose-acetate core 0.376-inch thick																
25T32	5.000	10.000	.0240	90.000	.116	3,100	29.30	None	153	36.6	153	...	605	660	173	159
25B32	5.000	10.000	.0240	92.000	.183	2,000	29.30	...do...	153	36.6	153	...	592	669	169	160
25T24	1.000	10.000	.0240	43.500	.157	2,300	55.00	Comp.	287 c	68.8	287	...	1,190	1,350	329	304
25B24	1.000	10.000	.0240	42.000	.087	4,200	47.40	...do...	247 c	59.3	247	...	862	1,091	246	253
25T16	.875	6.125	.0240	11.200	.161	6,100	80.50	...do...	257 c	100.6	257	...	1,010	1,130	285	261
25B16	.875	6.125	.0240	11.300	.180	5,400	85.30	...do...	272 c	106.7	272	...	1,030	1,168	289	269
25T12	.875	4.125	.0240	4.200	.212	9,900	100.00	Shear	215	125.0 s	213	...	775	875	222	206
25B12	.875	4.125	.0240	4.200	.213	9,900	95.00	...do...	204	118.8 s	202	...	735	810	210	191
25T8	.875	2.125	.0240	.983	.948	8,600 g	123.00	...do...	136	153.8 s	136	...	490	525	140	129
25B8	.875	2.125	.0240	1.333	1.098	7,400 g	122.50	...do...	136	153.2 s	136	...	500	535	143	131
Group 26 - Glass-cloth-laminate facings 0.024-inch thick; cellular cellulose-acetate core 0.249-inch thick																
26T32	5.000	10.000	.0240	202.000	.252	900	13.50	None	103	24.7	103	...	446	465	127	116
26B32	5.000	10.000	.0240	195.000	.192	1,200	13.80	...do...	105	25.3	105	...	442	470	127	117
26T24	1.000	10.000	.0240	88.800	.076	3,100	26.40	...do...	202	48.4	202	...	870	967	248	226
26B24	1.000	10.000	.0240	91.200	.113	2,100	25.20	...do...	192	46.2	192	...	820	890	234	209
26T16	.875	6.125	.0240	23.800	.171	3,700	59.00	Comp.	276 c	108.1	276	...	1,160	1,280	322	290
26B16	.875	6.125	.0240	23.800	.113	5,200	54.50	...do...	255 c	99.8	255	...	1,010	1,150	284	265
26T12	.875	4.125	.0240	8.550	.206	6,800	74.50	...do...	235 c	136.4 s	183	...	806	780	230	185
26B12	.875	4.125	.0240	8.200	.296	4,700	70.50	...do...	222 c	129.1 s	217	...	832	956	238	224
26T8	.875	2.125	.0240	2.020	.669	7,700 g	87.50	Shear	142	160.3 s	141	...	535	573	153	140
26B8	.875	2.125	.0240	2.040	.667	7,700 g	89.50	...do...	145	163.8 s	144	...	550	601	157	145
Group 27 - Glass-cloth-laminate facings 0.024-inch thick; paper honeycomb core 0.747-inch thick																
27T32	3.000	12.000	.0240	23.600	.142	...	81.80	Comp.	265 c	53.1	265	...	848	882	242	207
27B32	3.000	12.000	.0240	26.200	.011	...	76.50	...do...	248 c	49.7	248	...	890	900	253	211
27T24	1.000	10.000	.0240	11.200	.063	11,800	78.00	...do...	211 c	50.6	211	...	765	826	219	195
27B24	1.000	10.000	.0240	11.600	.103	7,300	100.20	Wrinkle	271 c	65.0	271	...	1,005	1,180	283	271
27T16	.875	6.125	.0240	3.050	.173	11,600	180.30	...do...	299 c	116.8	296	...	1,119	1,191	312	273
27B16	.875	6.125	.0240	3.100	.171	11,600	166.30	...do...	276 c	108.1	268	...	970	1,190	274	273
27T12	.875	4.125	.0240	.990	.052	84,400	295.00	Comp.	329 c	191.6	329	...	1,000	1,038	282	241
27B12	.875	4.125	.0240	1.130	.266	16,600	248.00	...do...	277 c	161.0	277	...	960	1,000	272	233
27T8	.875	2.125	.0240	.311	1.364	12,000 g	314.00	Shear	180	204.0 s	180	...	683	713	195	170
27B8	.875	2.125	.0240	.341	1.738	9,400 g	344.50	Comp.	198	223.7 s	198	...	343	404	98	103

Table 1.--Results of individual tests, the computed moduli of rigidity and shear strengths of the cores, the computed tensile and compressive strengths of the facings, and the stresses associated with the measured strains (continued)

Specimen number	Span a	Span b	Thickness of upper facing	Slope of load-deflection curve	$\eta \frac{h^2}{4b^2}$	Modulus of rigidity (computed)	Maximum load	Type of failure noted	Bending stress in thin facing at failure (computed)	Shear stress in core at failure (computed)	Computed stress in facing at load associated with largest strain measured: Thin facing	Computed stress in facing at load associated with largest strain measured: Thick facing	Largest strains measured in facings: Thin facing	Largest strains measured in facings: Thick facing	Stresses associated with largest strains: Thin facing	Stresses associated with largest strains: Thick facing
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
	In.	In.	In.	10⁻³ in. per lb.		P.s.i.	Lb.		100 p.s.i.	P.s.i.	100 p.s.i.	100 p.s.i.	10⁻⁵ in. per in.	10⁻⁵ in. per in.	100 p.s.i.	100 p.s.i.
Group 28 - Glass-cloth-laminate facings 0.024-inch thick; paper honeycomb core 0.627-inch thick																
28T32	3.000	12.000	0.0240	34.500	0.013	33,700	72.30	Comp.	278 c	55.5	278	....	862	1,163	246	257
28B32	3.000	12.000	.0240	39.000	.121	3,600	68.00	None	261	52.2	261	....	956	1,188	270	273
28T24	1.000	10.000	.0240	16.200	.095	6,500	74.30	Comp.	238 c	57.0	238	....	993	1,020	280	237
28B24	1.000	10.000	.0240	16.800	.153	4,100	76.00	...do..	243 c	58.3	243	....	893	1,045	252	243
28T16	.875	6.125	.0240	4.360	.198	8,400	125.50	...do..	246 c	96.3	246	....	940	1,038	267	241
28B16	.875	6.125	.0240	4.640	.278	5,900	130.00	...do..	255 c	99.7	255	....	960	1,140	272	263
28T12	.875	4.125	.0240	1.570	.276	13,400	233.00	Shear	308 c	178.8	308	....	893	1,070	254	248
28B12	.875	4.125	.0240	1.750	.458	8,000 g	218.00	Comp.	288 c	167.2	288	....	1,020	1,155	287	266
28T8	.875	2.125	.0240	.506	2.042	6,700 g	224.00	Shear	152	171.9 s	152	....	567	609	162	147
28B8	.875	2.125	.0240	.494	1.870	7,300 g	228.00	...do..	155	175.0 s	148	....	558	613	160	148
Group 29 - Glass-cloth-laminate facings 0.024-inch thick; paper honeycomb core 0.495-inch thick																
29T32	3.000	12.000	.0240	62.700	.142	2,400	37.30	None	180	36.0	180	....	719	768	205	182
29B32	3.000	12.000	.0240	62.000	.082	4,100	43.00	None	205	41.0	205	....	828	965	237	225
29T24	1.000	10.000	.0240	25.200	.070	7,000	50.50	Wrinkle	203 c	48.7	203	....	775	857	222	202
29B24	1.000	10.000	.0240	22.500	-.066	....	73.80	Comp.	296 c	71.1	296	....	1,015	1,135	286	212
29T16	.875	6.125	.0240	6.670	.131	9,900	64.50	...do..	159 c	62.1	159	....	628	640	180	154
29B16	.875	6.125	.0240	6.600	.158	8,300	141.50	...do..	348 c	136.4	348	....	1,255	1,510	345	332
29T12	.875	4.125	.0240	2.440	.172	16,400	96.80	...do..	160 c	93.4	160	....	615	610	176	147
29B12	.875	4.125	.0240	2.460	.201	14,100	179.00	Tension	297	172.7	297	....	1,115	1,505	311	332
29T8	.875	2.125	.0240	.590	.954	11,400 g	204.50	Shear	175	197.1 s	175	....	630	645	180	155
29B8	.875	2.125	.0240	.550	.775	14,100 g	229.50	...do..	196	221.3 s	196	....	612	690	175	165

Table 2.—Computed stresses in glass-fabric-laminate facings compared with those obtained from strains

Specimen group	Thin or top facing				Thick or bottom facing			
	Formula	Strain	Ratio	Number of tests	Formula	Strain	Ratio	Number of tests
	P.s.i.	P.s.i.			P.s.i.	P.s.i.		
				Balsa-wood cores				
1	23,800	21,500	0.903	12	7,000	8,300	1.186	12
2	28,400	24,700	.869	10	14,500	14,700	1.013	10
3	20,500	20,900	1.020	12	17,000	16,800	.988	12
4	19,800	18,300	.925	12	19,800	16,000	.803	12
21	21,100	21,800	1.032	10	21,100	20,900	.991	10
22	20,500	23,200	1.131	10	20,500	21,200	1.032	10
23	16,600	19,900	1.199	8	16,600	17,900	1.078	8
Av.	....	....	1.001	74	....	....	1.010	74
				Cellular cellulose-acetate cores				
24	16,700	17,300	1.036	8	16,700	16,200	.970	8
25	20,600	22,100	1.072	10	20,600	20,600	1.000	10
26	18,200	21,200	1.165	10	18,200	19,200	1.055	10
Av.	....	....	1.022	28	....	....	1.011	28
				Paper honeycomb cores				
27	25,400	24,300	.957	10	25,400	21,800	.858	10
28	24,200	24,500	1.012	10	24,200	23,200	.959	10
29	22,200	23,200	1.044	10	22,200	21,600	.973	10
Av.	....	....	1.004	30	....	....	.930	30

Table 3.--Computed stresses in aluminum facings compared with those obtained from stains

Specimen group	Thin or top facing				Thick or bottom facing			
	Formula	Strain	Ratio	Number of tests	Formula	Strain	Ratio	Number of tests
	P.s.i.	P.s.i.			P.s.i.	P.s.i.		
				Balsa-wood cores				
5	43,400	40,800	0.941	7	19,800	24,400	1.232	12
6	30,400	32,500	1.069	7	25,100	28,100	1.120	12
7	41,100	40,800	.993	7	41,100	41,400	1.032	7
8	41,700	41,300	.991	3	33,900	37,600	1.109	11
8A	43,900	45,300	1.031	5	32,800	37,000	1.129	10
11	34,000	34,600	1.018	9	34,000	35,000	1.029	9
12	34,400	34,600	1.006	8	32,200	36,900	1.145	7
13	37,800	39,400	1.042	9	38,900	41,400	1.064	10
14	40,200	36,400	.906	5	40,200	39,900	.993	5
Av.	....	....	1.004	60	....	....	1.106	83
				Cellular cellulose-acetate cores				
9	28,400	28,600	1.007	5	14,900	18,700	1.256	8
15	25,600	26,100	1.020	10	25,600	27,000	1.054	10
16	23,800	25,500	1.071	10	23,800	25,600	1.076	10
17	29,000	30,300	1.045	6	29,000	33,200	1.144	6
18	30,000	30,400	1.013	8	30,000	30,000	1.000	8
Av.	....	....	1.034	39	....	....	1.100	42
				Paper honeycomb cores				
10	48,100	46,100	.959	5	22,000	25,500	1.159	12
19	27,700	27,900	1.007	10	27,700	31,000	1.120	10
20	31,400	31,500	1.002	10	31,400	35,000	1.115	10
Av.	....	....	0.995	25	....	....	1.133	32

Table 4.--Compressive strength of glass-fabric-laminate facings

Specimen group	Facing thickness	Core thickness	Ratio	Compressive strength	Number of tests
	Inch	Inch		P.s.i.	
		Balsa-wood cores			
1	0.0060	0.251	41.8	19,400	6
4	.0100	.750	75.0	19,800	12
2	.0105	.377	35.9	20,000	4
3	.0170	.504	29.6	20,300	3
21	.0240	.498	20.8	22,400	6
22	.0240	.374	15.6	24,900	6
23	.0240	.247	10.3	19,300	7
3	.0250	.504	20.2	26,400	4
Av.	....	....	....	21,100	47
		Cellular cellulose-acetate cores			
24	0.024	0.498		18,500	6
25	.024	.376		26,600	4
26	.024	.249		19,700	4
Av.	....	....		21,200	14
		Paper honeycomb cores			
27	0.024	0.747		27,200	8
28	.024	.627		26,500	7
29	.024	.495		23,300	5
Av.	....	....		26,000	20
		From Forest Products Laboratory Report No. 1821			
	0.125	0		20,800	6
		(Compressive stress at proportional limit)			
	.125	0		37,800	6
		(Compressive strength)			

Table 5.--Compressive strength of aluminum facings

Specimen group	Facing thickness	Core thickness	Ratio	Compressive strength	Number of tests
	Inch	Inch		P.s.i.	
		Balsa-wood cores			
12	0.032	0.390	12.2	50,000	1
13	.020	.257	12.8	51,000	2
11	.032	.506	15.8	49,700	3
14	.012	.260	21.7	57,800	5
8A	.012	.501	41.7	64,700	2
8	.012	.505	42.1	58,800	4
7	.012	.744	62.0	58,300	5
5	.012	.757	63.1	58,400	7
Av.	....	....	....	57,100	29
		Cellular cellulose-acetate cores			
16	0.032	0.370	11.6	33,700	4
17	.020	.244	12.2	40,200	1
15	.032	.496	15.5	35,200	4
18	.012	.247	20.6	40,300	3
9	.012	.502	41.8	52,100	4
Av.	....	....	....	40,700	16
		Paper honeycomb cores			
20	0.032	0.634	19.8	44,700	4
19	.032	.755	23.6	40,100	4
10	.012	.746	62.1	60,600	3
Av.	....	....	....	47,400	11
		From Forest Products Laboratory Report No. 1817			
	0.032	....	....	73,000	....
	.012	....	....	54,000	....

Table 6.--Tensile strength of glass-fabric-laminate facings on balsa cores

Specimen group	Facing thickness	Core thickness	Tensile strength	Number of tests
	Inch	Inch	P.s.i.	
1	0.0060	0.251	35,800	4
2	.0105	.337	44,100	4
Av.	....	....	40,000	8
	From Forest Products Laboratory Report No. 1821			
	0.125	0	39,300	6

Table 7.--Tensile strength of aluminum facings

Specimen group	Facing thickness	Core thickness	Tensile strength	Number of tests
	Inch	Inch	P.s.i.	
8	0.012	0.505	65,600	1
8A	.012	.501	65,000	1
Av.	....	....	65,300	2
	From National Advisory Committee for Aeronautics Technical Note No. 1512			
	0.032	0	68,400 (Longitudinal)	2
	.032	0	65,800 (Transverse)	2

Table 8.--Shear strength and modulus of rigidity of balsa-wood cores

Specimen group	Facing thickness		Core thickness	Average shear strength						Average modulus of rigidity			
				Without spec. 8	Number of tests	Of spec. 8	Number of tests	Shear tests	Ratio	Bending tests	Number of tests	Shear tests	Ratio
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	Inch	Inch	Inch	P.s.i.		P.s.i.		P.s.i.		P.s.i.		P.s.i.	
				Aluminum facings									
11	0.032	...	0.506	201.5	4	233.0	2	...	...	13,000	4	...	...
12	.032	...	.390	224.0	4	253.5	2	...	...	12,400	3	...	...
13	.020	...	.275	200.4	2	215.8	2	...	...	11,200	4	...	...
14	.012	...	.260	...	0	187.6	2	...	...	15,200	2	...	...
7	.012	...	.744	147.3	4	193.1	2	240	1.63	12,000	5	20,100	1.68
8	.012	0.019	.505	196.7	3	212.8	2	258	1.31	13,800	6	19,300	1.40
8A	.012	.019	.501	181.4	3	216.0	2	...	...	13,100	4	...	...
5	.012	.0305	.757	170.5	4	145.6	2	216	1.27	15,000	4	22,900	1.53
6	.020	.031	.753	166.0	6	157.7	2	245	1.48	12,200	6	15,300	1.24
Av.	...	...	...	183.5	30	201.7	18	...	1.42	13,000	38	...	1.46
				Glass-fabric-laminate facings									
21	.024	...	.498	...	0	185.6	2	...	...	8,800	2	...	...
22	.024	...	.374	...	0	164.6	2	...	...	7,800	2	...	...
23	.024	...	.274	...	0	249.2	2	...	...	8,300	2	...	...
Av.	...	...	...	...	...	199.8	6	...	...	8,300	...	...	...

Table 9.--Shear strength and modulus of rigidity of cellular cellulose-acetate cores

Specimen group	Facing thickness		Core thickness	Average shear strength						Average modulus of rigidity			
				Without spec. 8	Number of tests	Of spec. 8	Number of tests	Shear tests	Ratio	Bending tests	Number of tests	Shear tests	Ratio
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	Inch	Inch	Inch	P.s.i.		P.s.i.		P.s.i.		P.s.i.		P.s.i.	
						Aluminum facings							
15	0.032	…	0.496	143.8	4	173.0	2	…	…	7,400	4	…	…
16	.032	…	.370	131.2	4	143.4	2	…	…	3,700	7	…	…
17	.020	…	.244	141.2	2	204.2	2	…	…	6,700	4	…	…
18	.017	…	.247	70.1	4	149.2	1	…	…	3,400	4	…	…
9	.012	0.031	.502	95.4	4	112.6	2	128	1.34	4,800	4	5,100	1.06
Av.	…	…	…	113.7	18	149.4	9	…	…	5,000	23	…	…
						Glass-fabric-laminate facings							
24	.024	…	.498	…	0	140.0	2	…	…	7,000	2	…	…
25	.024	…	.376	121.9	2	153.5	2	…	…	8,000	2	…	…
26	.024	…	.249	132.8	2	162.0	2	…	…	7,700	2	…	…
Av.	…	…	…	127.4	4	151.8	6	…	…	7,600	6	…	…

Table 10.--Shear strength and modulus of rigidity of paper honeycomb cores

Specimen group	Facing thickness		Core thickness	Average shear strength						Average modulus of rigidity			
				Without spec. 8	Number of tests	Of spec. 8	Number of tests	Shear tests	Ratio	Bending tests	Number of tests	Shear tests	Ratio
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	Inch	Inch	Inch	P.s.i.		P.s.i.		P.s.i.		P.s.i.		P.s.i.	
				Aluminum facings									
19	0.032	......	0.755	150.0	4	165.1	2	......	....	7,800	7	......	......
20	.032	......	.634	171.0	4	201.6	2	......	....	9,100	4	......	......
10	.012	0.030	.746	184.0	4	249.4	2	226	1.23	13,800	4	24,600	1.78
Av.	......	......	......	168.3	12	205.4	6	......	....	9,700	15	......	......
				Glass-fabric-laminate facings									
27	.024	......	.747	......	0	213.8	2	......	....	10,700	2	......	......
28	.024	......	.627	......	0	173.4	2	......	....	7,300	3	......	......
29	.024	......	.495	......	0	209.2	2	......	....	12,800	2	......	......
Av.	......	......	......	......	......	198.6	6	......	....	9,800	7	......	......

Table 11.--Moduli of rigidities obtained from sandwich strips having 0.02-inch aluminum facings and tested as centrally loaded beams compared with those obtained from shear tests

Balsa-wood cores

Specimen number (1)	Modulus of rigidity: Beam tests (2)	Modulus of rigidity: Shear tests (3)
	P.s.i.	P.s.i.
Cores 3/16-inch thick		
$\eta \frac{h^2}{4b^2}$ from 0.064 to 0.707		
1ABS0	14,400	13,540
	9,800	15,480
1ABS15	14,700	16,700
	11,210	11,570
1ABS30	14,700	15,350
	14,600	11,980
1ABS45	8,500	12,340
	10,900	14,850
1ABR0	16,400	16,890
	13,400	24,680
1ABR30	8,760	13,040
	11,900	12,890
1ABR60	13,200	15,040
	10,900	25,900
1ABR90	11,300	14,400
	13,300	20,960
Av.	12,370	15,970
Ratio		1.29
Cores 5/16-inch thick		
$\eta \frac{h^2}{4b^2}$ from 0.013 to 0.433		
2ABS0	18,100	20,110
	13,700	34,500
2ABS15	14,900	19,800
	13,400	15,690
2ABS30	11,500	24,700
	11,800	17,550
2ABS45	10,900	14,920
	10,600	18,200
2ABR0	15,500	15,400
	11,800	13,500
2ABR30	14,000	23,820
	10,700	17,100
2ABR60	22,400	13,080
	10,700	28,500
2ABR90	11,600	18,100
	15,400	19,250
Av.	13,570	19,630
Ratio		1.45
Cores 3/8-inch thick		
$\eta \frac{h^2}{4b^2}$ from 0.153 to 0.944		
3ABS0	10,900	13,200
	13,400	16,540
3ABS15	10,200	19,380
	12,500	15,640
3ABS30	12,800	9,830
	10,000	11,300
3ABS45	13,300	13,060
	10,500	19,450
3ABR0	19,300	28,800
	16,900	19,250
3ABR30	12,000	13,760
	12,600	16,400
3ABR60	12,600	16,700
	11,400	16,480
3ABR90	11,600	8,910
	12,300	14,300
Av.	12,650	15,690
Ratio		1.24
Av. ratio		1.33

Hard sponge-rubber cores

Specimen number (4)	Modulus of rigidity: Beam tests (5)	Modulus of rigidity: Shear tests (6)
	P.s.i.	P.s.i.
Cores 3/16-inch thick		
$\eta \frac{h^2}{4b^2}$ from 0.241 to 2.930		
1AHS30	4,075	4,790
	4,105	3,640
1AHS45	2,605	2,660
	2,835	3,320
1AHR0	4,390	1,620
	4,880	1,440
1AHR90	1,260	5,970
	3,025	3,320
Av.	3,397	3,365
Ratio		0.99
Cores 5/16-inch thick		
$\eta \frac{h^2}{4b^2}$ from 0.383 to 1.822		
2AHS0	3,120	5,300
	2,105	6,330
2AHS15	1,970	3,450
	4,070	2,710
2AHR0	3,795	2,310
	2,485	4,110
2AHR30	3,585	4,320
	3,060	4,440
2AHR60	4,115	4,300
	3,335	5,290
2AHR90	4,475	3,860
Av.	3,201	4,222
Ratio		1.32
Av. ratio		1.17

Cellular cellulose-acetate cores

Specimen number (7)	Modulus of rigidity: Beam tests (8)	Modulus of rigidity: Shear tests (9)
	P.s.i.	P.s.i.
Cores 3/8-inch thick		
$\eta \frac{h^2}{4b^2}$ from 0.303 to 6.015		
3AHS0	7,950	5,510
	5,210	1,087
3AHS15	3,625	2,910
	2,575	6,930
3AHS30	3,645	4,230
	2,065	4,710
3AHS45	2,445	4,240
	5,645	4,190
3AHR0	5,255	3,060
	2,435	5,760
3AHR30	4,095	4,780
	2,410	5,900
3AHR60	5,735	5,030
	2,760	4,070
3AHR90	3,305	7,180
	2,810	2,720
Av.	3,872	4,520
Ratio		1.17

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Table 12.--Moduli of rigidity of specimen having 0.032-inch aluminum facings and a 0.489-inch cellular cellulose-acetate core

Distance of mirrors from central load	Moduli of rigidity				
	From mirrors				From shear tests
	Right end	Left end	Individual values divided by average		
In.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.
					3,100
3	3,930	3,190	0.975	0.792	3,250
6	4,525	4,410	1.123	1.094	3,200
9	4,060	4,060	1.008	1.008	3,200
Av.	4,030		....	....	3,200

Table 13.--Moduli of rigidity of specimen having 0.032-inch aluminum facings and a 0.505 end-grain balsa-wood core

Distance of mirrors from central load	Moduli of rigidity				
	From mirrors				From shear tests
	Right end	Left end	Individual values divided by average		
In.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.
2	21,500	24,800	0.791	0.912	30,300
4	23,200	31,500	.853	1.158	31,700
6	30,600	17,500	1.125	.644	29,400
8	45,000	23,400	1.655	.860	25,100
Av.	27,200		....	....	29,100

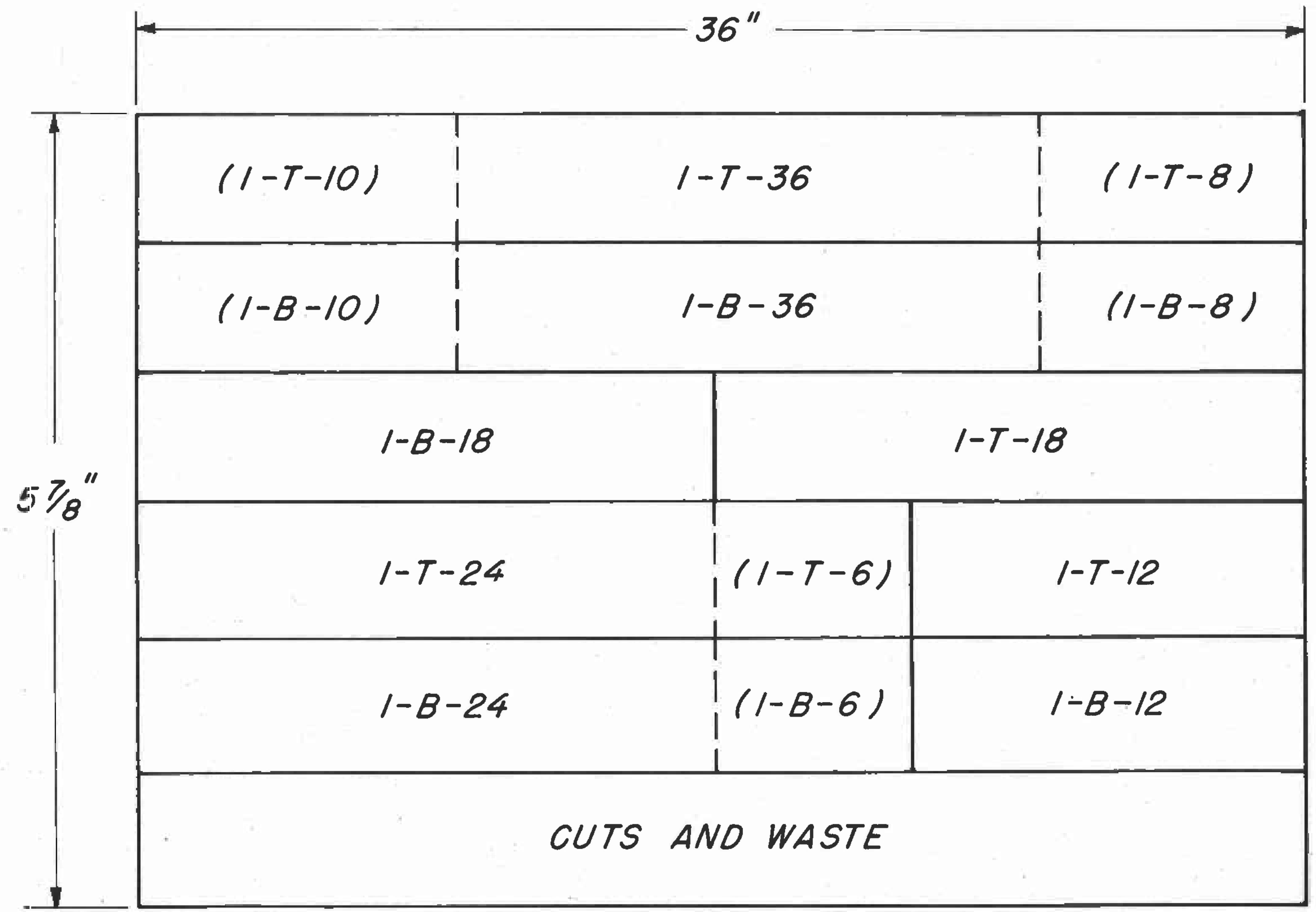

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Figure 1.--Cutting diagram for groups 1 to 10.

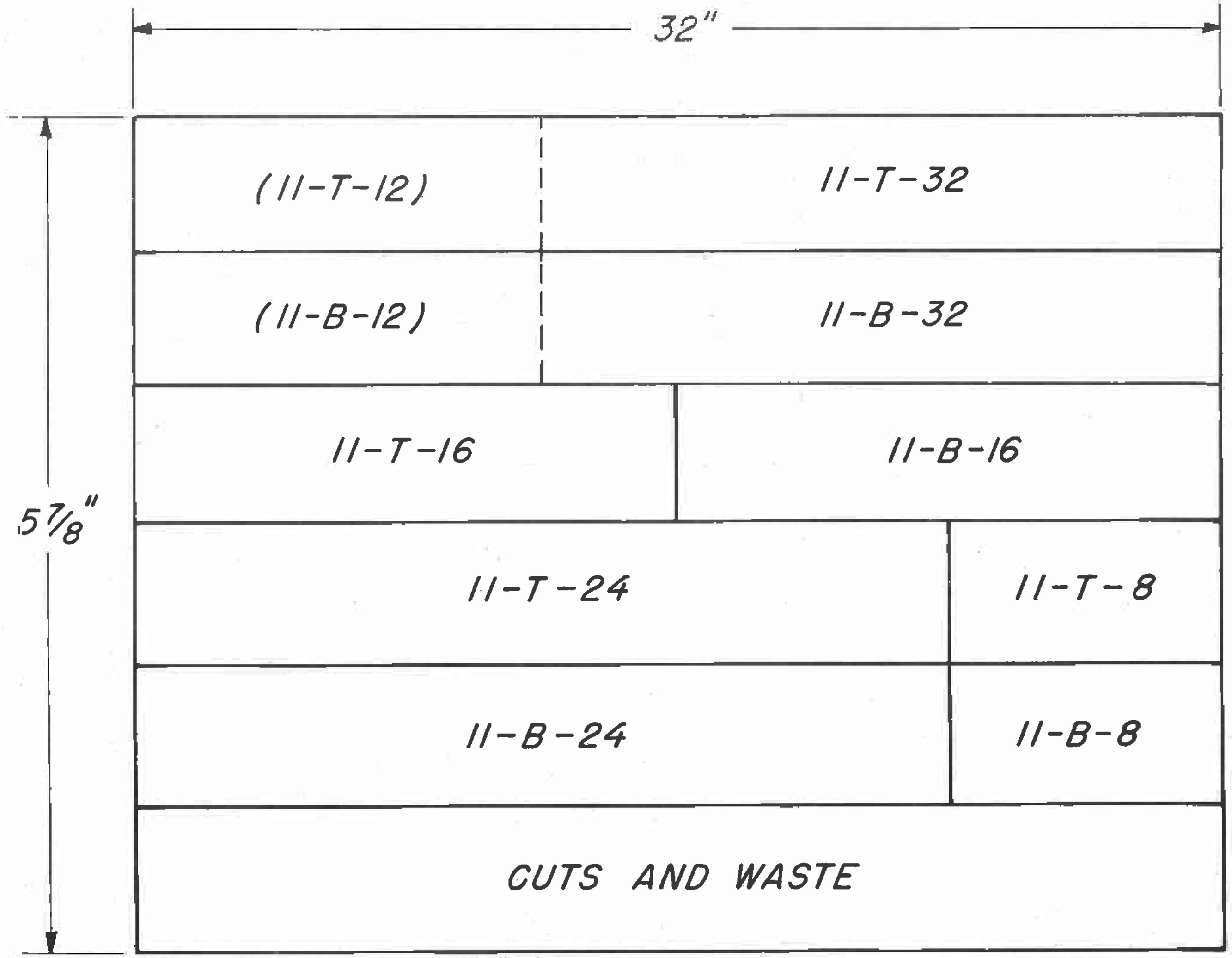

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Figure 2.--Cutting diagram for groups 11 to 29.

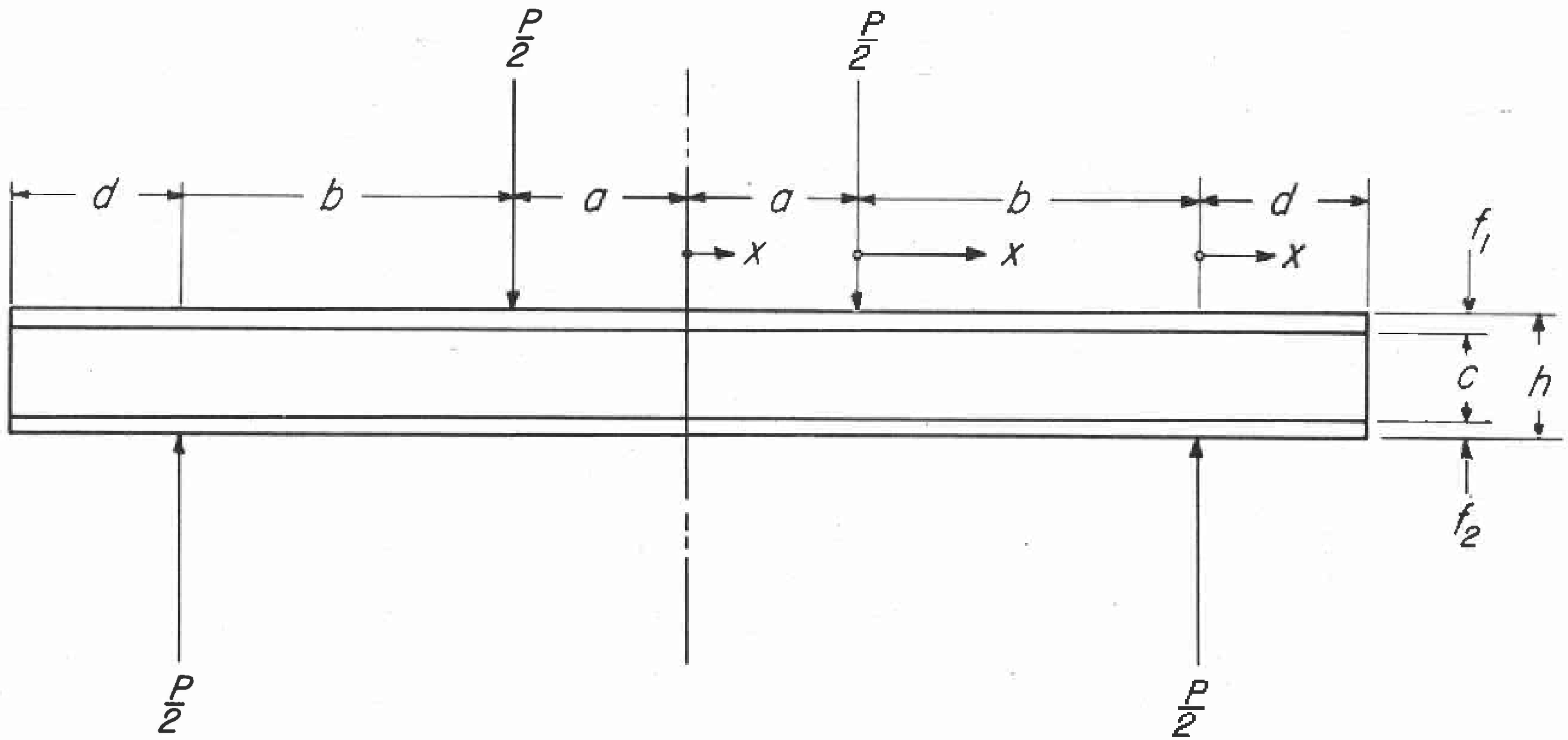

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Figure 3.--Sketch of test specimen.

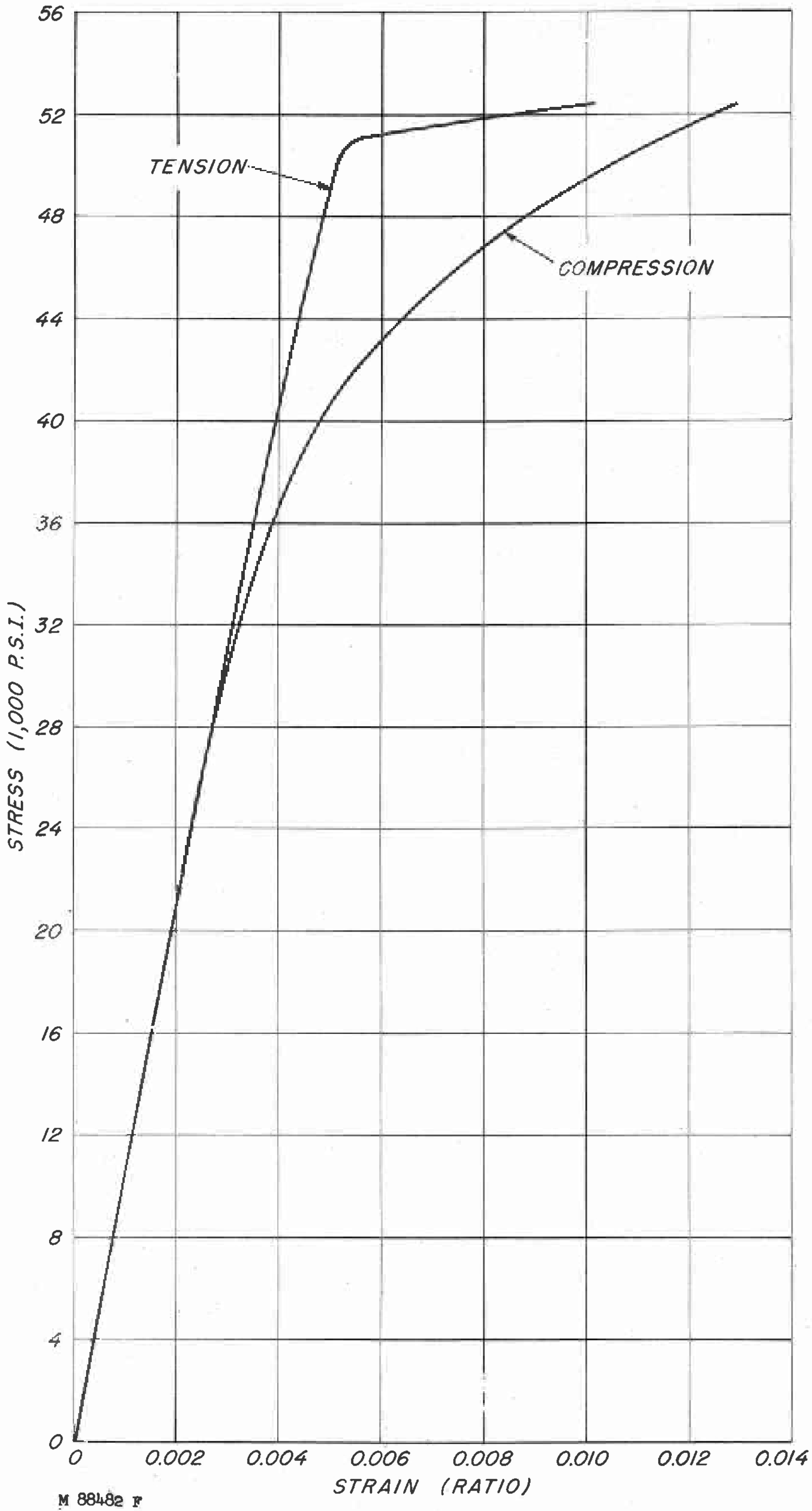

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Figure 4.--Stress-strain curves of 24ST sheet aluminum (from figure 1, N.A.C.A. Technical Note No. 1512).

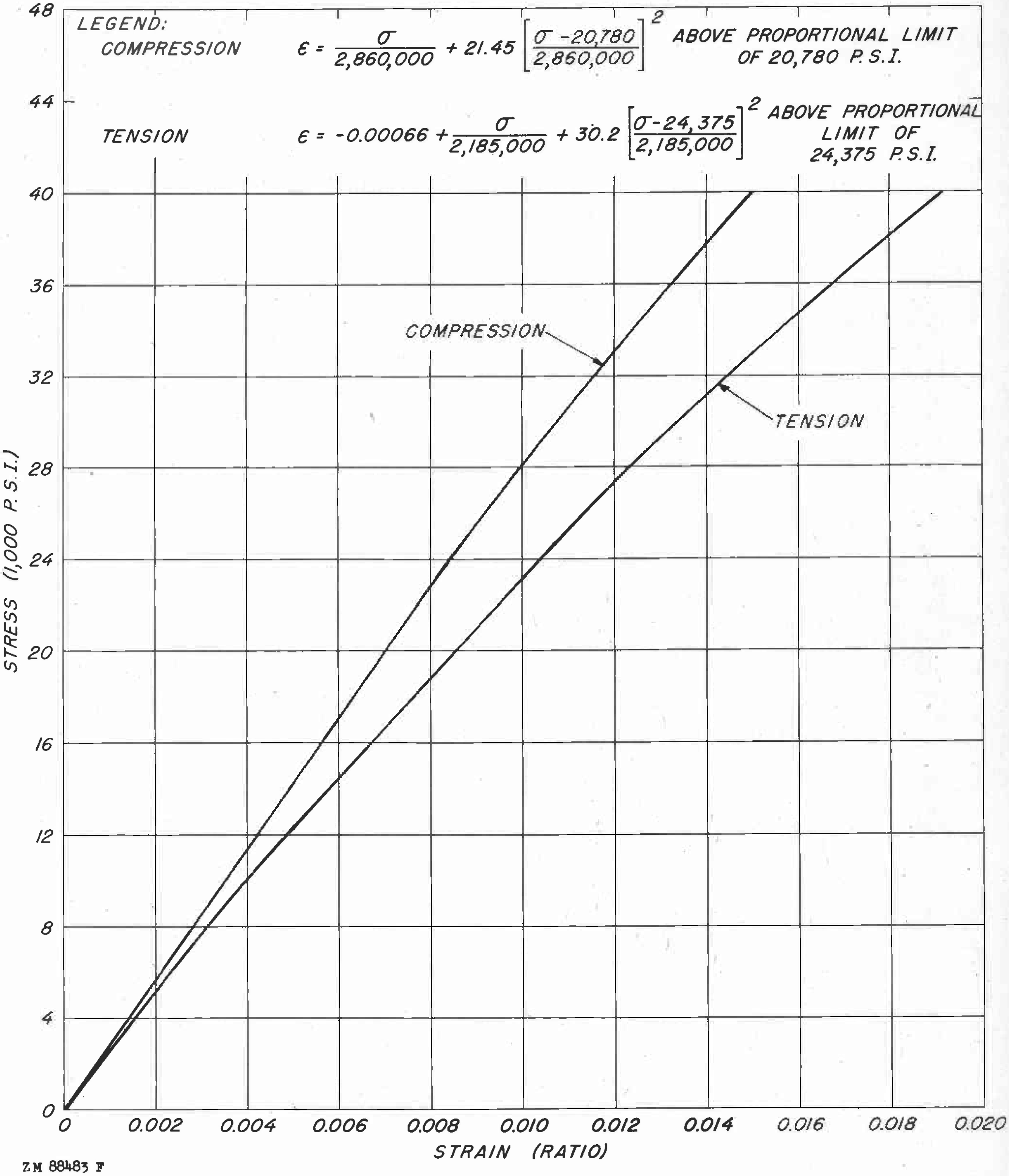

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Figure 5.--Stress-strain curve of 112-114 glass-cloth laminate, cross-laminated (from Forest Products Laboratory Report No. 1821 data).

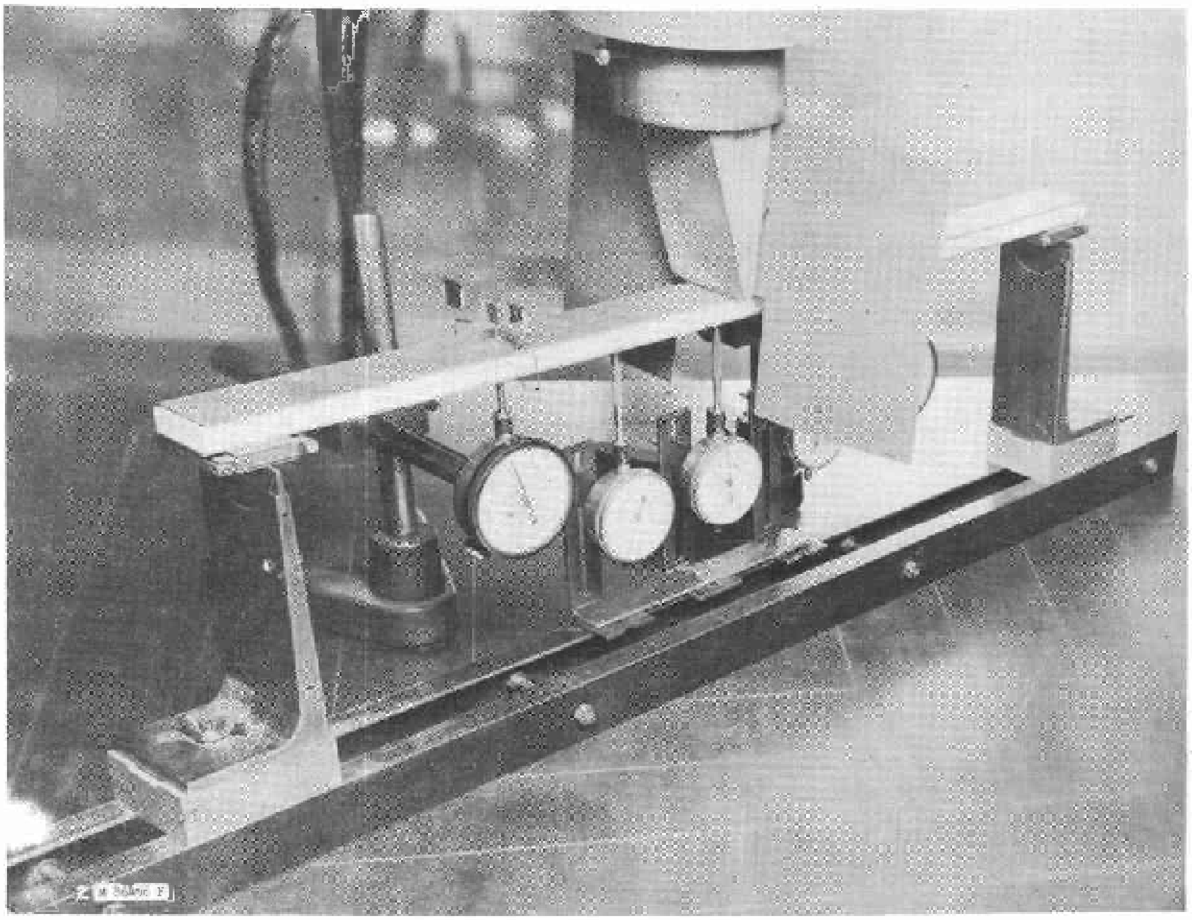

Figure 6.--Illustration of test apparatus for two supplementary tests.

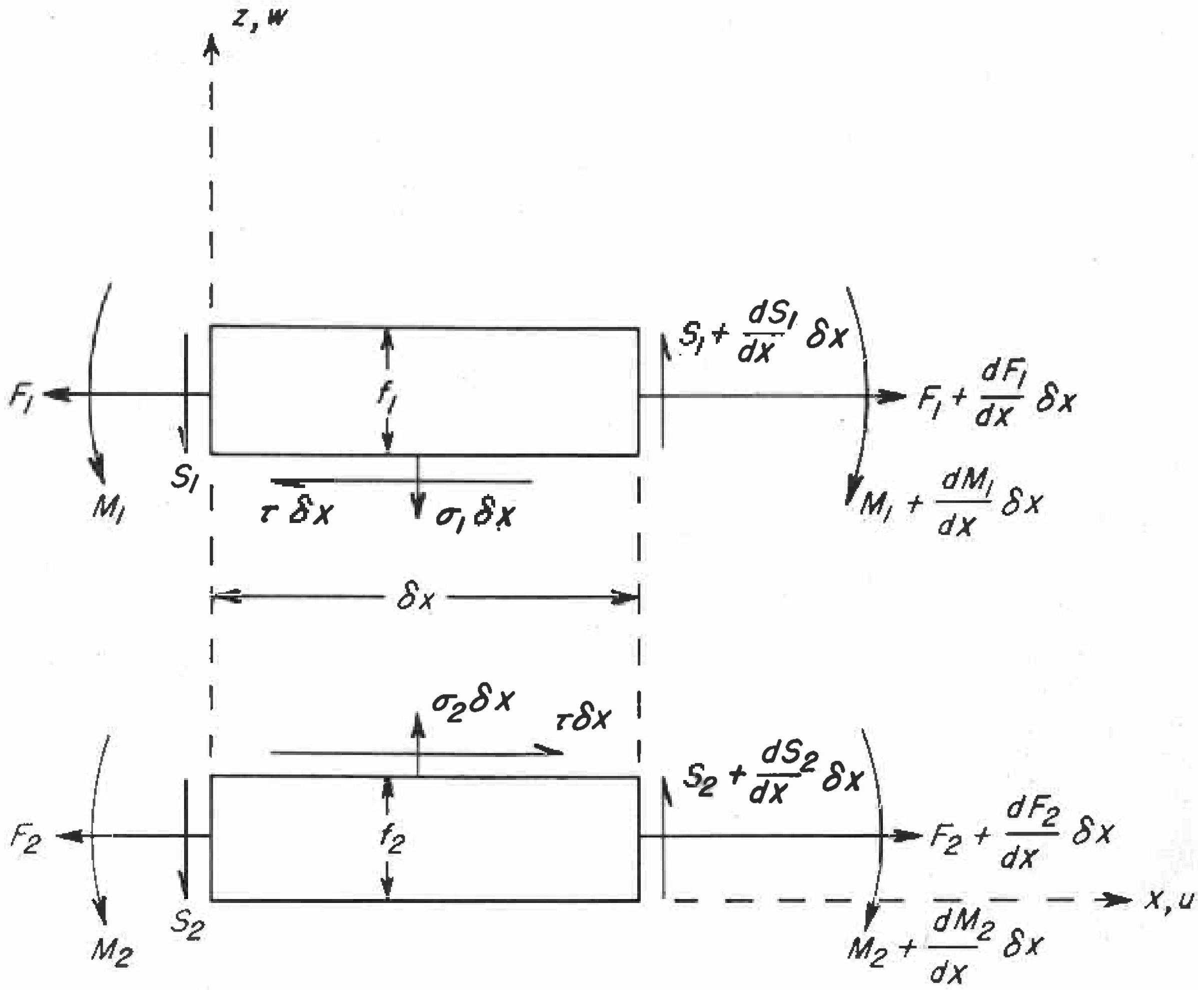

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Figure 7.--Element of sandwich strip.