

EFFECT OF CORE THICKNESS ON SHEAR PROPERTIES OF ALUMINUM HONEYCOMB CORE

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EFFECT OF CORE THICKNESS ON SHEAR PROPERTIES
OF ALUMINUM HONEYCOMB CORE¹

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Abstract

The effect of variations in thickness from 1/2 inch to 4 inches on shear properties of an aluminum honeycomb core was evaluated. Preparation of shear specimens and evaluation procedures are described. Results showed that shear strength parallel to the core ribbon direction decreased 36 percent and shear strength perpendicular to the core ribbon direction decreased 23 percent as core thickness increased from 1/2 inch to 4 inches. Shear properties of 1/2-inch-thick core were identical whether determined by tension or compression loading.

Introduction

Sandwich constructions, comprised of strong thin facings bonded to a thick lightweight core, can be used to produce stiff lightweight structural panels for use in flight vehicles. Such panels may be subjected to shear loadings. Much of the design data for cores has already been obtained for cores of about one-half inch in thickness. The purpose of this study is to determine the effects of core thickness on the shear properties of aluminum honeycomb core so that constructions of any thickness can be properly designed.

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

A core with 3/8-inch cells was selected because criteria for buckling of the cell wall predicts that core thickness has a greater effect on shear strength of a core with this cell size than on that of a core with smaller cells. A foil of nominal 0.002-inch thickness was chosen so that loads for the bigger specimens would not be excessive.

The existing data on shear properties of 1/2-inch-thick cores had been obtained by tension loading of plates to which were bonded core specimens 6 inches long. For the thicker and longer specimens evaluated in this study, however, compression loading was more practical because it would have been necessary to design and construct fixtures for tension loading. In order to relate the results of this study to those of previous studies, therefore, both tension and compression loadings were employed in the evaluation of the 1/2-inch-thick cores used in this study. These results were compared to determine if the method of loading had any effect on the data.

Core Material Used

The aluminum core that was used was an expanded core of 3003-H19 aluminum alloy foil 0.0024 inch thick, which was bonded together with a high-temperature-setting adhesive of the vinyl-phenolic type. The core was expanded to form a large block having 3/8-inch hexagonal cells. The foil was pierced with fine holes to allow escape of solvent during bonding of sandwich. Slices of core that were cut to various thicknesses from the same core block were furnished by the manufacturer.

Preparation of Specimens

Shear specimens were cut from core slices with a high-speed bandsaw. The specimens for compression loading were 4 inches wide and 12 times their thicknesses in length, the thicknesses used being 1/2 inch, 1, 2, and 4 inches. The specimens for tension loading were 2 by 6 inches by 1/2 inch thick. For each core thickness and method of loading, a half of the specimens had core ribbons parallel to the direction of loading and the remainder had core ribbons perpendicular to the direction of loading.

Steel loading plates were bonded to the core with a room-temperature-setting epoxy resin (fig. 1). The core cell ends contacted the loading plates and the resin-formed fillets, which bonded the cell walls to the plates.

The loading plates were stiff enough to resist bending. A stiffness of at least 600,000 pounds³ per square inch for each inch of width and core thickness is recommended.³ On this basis, required loading plate thicknesses were calculated as follows:

<u>Core thickness</u> (Inch)	<u>Required loading plate thickness</u> (Inch)	<u>Loading plate thickness used</u> (Inch)
0.5	0.49	0.50
1.0	.62	.75
2.0	.78	1.00
4.0	.99	1.25

Evaluation Procedures

The arrangement of shear specimens and loading plates is shown in the sketch of figure 1. The plane of action of the load passed diagonally through opposite corners of the core specimen. Because the length of each specimen was 12 times its thickness, the angle at which the load plane intersected the specimens was always the same.

Compression Loading

Figure 2 shows the core shear test setup used for compression loading. The specimens with attached loading plates were mounted between notched blocks placed at the upper platen of a testing machine and a lower spherical bearing block. An initial load of about 200 pounds was applied, and the loading plates were firmly and evenly seated in the notched blocks by tapping the spherical bearing block with a hammer. Screw jacks were then placed at the four corners of the spherical bearing block (fig. 2) to prevent movement of the block during application of load. The movable head of the testing machine was driven at a speed of about 0.01 inch per minute per inch of specimen thickness, and failure of the specimens occurred in 3 to 6 minutes.

Movement of one loading plate with respect to the other was measured to 0.0001 inch by a collar and dial gage. The aluminum collar was attached to

³American Society for Testing and Materials, Shear Test in Flatwise Plane of Flat Sandwich Constructions or Sandwich Cores, ASTM Standard C273-61, 1961.

one loading plate with set screws, while the dial gage was similarly fastened to the other loading plate. The spring-loaded dial stem maintained contact with the collar. The collar and dial gage were mounted so that they moved away from each other as the specimen deformed, thus preventing damage to the dial when failure occurred.

Failure occurred by progressive buckling of the core cell walls followed by crinkling of the cell corners.

Following failure, each specimen was cut in two, parallel to the loading plates. The plates were heated until the epoxy resin and attached core separated cleanly from the plate surface. Several cuts were made across the width of each piece of core with a bandsaw, and the glue line thickness at the cell walls was measured with a scale.

Figure 3 shows the test setup that was used for compression loading of large (2- and 4-inch-thick cores) shear specimens. This setup was identical to that shown in figure 2 except that slack safety chains were employed to prevent possible falling of the heavy test specimen at failure or upon subsequent removal of load.

Tension Loading

A shear specimen and apparatus for tension loading are shown in figure 4. Loads were transmitted to the loading plates through universal joints as shown. The movable head of the testing machine was driven at a rate of about 0.01 inch per minute, and specimen failures occurred within 3 to 6 minutes. The rate of loading was greater than that for the 1/2-inch-thick specimens evaluated by compression loading because of lost motion in the tension-loading apparatus. Relative motion of the loading plates was measured to 0.0001 inch with the collar and dial gage (fig. 4). Failure occurred by progressive buckling of the core cell walls followed by crinkling of the cell corners. Glue line thicknesses were measured after failure as previously described.

Presentation of Data and Discussion of Results

Shear data are presented in table 1. The small differences in specimen density probably represent differences in the degree of expansion of the cells, because all specimens came from the same block of unexpanded core. Average values of shear properties were adjusted to a common core density by multiplying by the ratio of 2.90 pounds per cubic foot to the specimen density average.

Shear strains in the core that were used for computing the shear modulus were determined by dividing the total deformation measured between loading plates by an effective thickness of the core. This effective thickness was computed by deducting twice the average thickness of the bonding resin between the core and loading plates from the total core thickness. This calculation was based on the assumption that the loading plates and portions of the core reinforced by adhesive were very stiff compared to the remainder of the core. The effective core thickness was found to be about 80 percent of total core thickness for the cores evaluated using tension loading and about 95 percent for the cores evaluated using compression loading.

Comparison of Results on 1/2- inch-thick Cores Only

Data for the tension and compression loadings of 1/2-inch-thick cores compared closely, the maximum difference being about 4 percent. The close agreement between shear modulus values in spite of considerable difference in bond thickness tends to verify the method used to determine effective core thickness.

Shear data for 1/2-inch-thick cores compared closely to that obtained previously during a more extensive evaluation of aluminum honeycomb cores.⁴ For shear in the LT plane (parallel to core ribbon direction), only the cell walls parallel to the applied load are considered capable of carrying stress. From cell geometry, the ratio of load-carrying foil area to core area is found to be $\frac{4t}{3S}$, where t is the foil thickness (0.0024 inch) and S is the cell size ($3/8$ inch). The maximum foil shear stress in the previous studies was 23,900 pounds per square inch ± 8 percent. This corresponds to a core shear stress of 204 ± 16 pounds per square inch, the lower limit of which compares closely with the 188- and 182-pounds-per-square-inch values in table 1. Foil shear stress at proportional limit in the previous studies was found to be 12,300 pounds per square inch ± 15 percent. This is equivalent to a core shear stress of 105 ± 16 pounds per square inch, which agrees with 100 pounds per square inch obtained in this study.

For aluminum cores, a formula used for determining the shear modulus⁴ is $G_{LT} = 5,160,000 t/S$. This gives values about 15 percent lower than results obtained in this study, probably because the contributions to stiffness of cell walls inclined to the load are ignored. Using this formula for the core evaluated in this study, the shear modulus was 38,000 pounds per square inch, which agrees with the values in table 1.

⁴-Kuenzi, E. W. Mechanical Properties of Aluminum Honeycomb Cores. Forest Products Laboratory Report No. 1849, 1955.

For shear in the WT plane (perpendicular to the core ribbon direction), the maximum shear stress was 54 percent, proportional limit stress was 53 percent, and shear modulus was 48 percent of that for the LT plane. These results agree roughly with those determined in the previous studies.

Comparison of Results on Cores of Varying Thicknesses

The effect of core thickness on maximum shear stress is shown in figure 5. In the LT plane, core shear stress was 185 pounds per square inch for 1/2-inch-thick cores and about 36 percent less for 4-inch-thick cores. From the slope of the curve, it is apparent that further reduction in strength occurs as core thickness increases beyond 4 inches, perhaps to about 6 inches.

When applied to the cell walls, buckling criteria are useful for predicting the effect of changing core thickness on the shear properties of the core. The cell walls parallel to the direction of loading, which carry most of the shear load, are composed of two thicknesses of aluminum foil, tightly bonded together. Two opposite edges of these cell walls are bonded to the loading plates. The other two edges are each held in place by a pair of single-foil-thick cell walls at a 60° angle, one on each side of the double-cell wall. Under the action of shear loads, the single-foil walls tend to buckle first, reducing the edge support of the double-cell walls and reducing their ability to carry load. The buckling stress formula for a simply supported homogeneous plate subjected to edgewise shear is applicable to a cell wall and may be written as⁵

$$\tau = L_o \frac{\pi^2 E}{12 (1-\mu^2)} \frac{h^2}{a^2} \quad (1)$$

where τ is the buckling stress, E is the modulus of elasticity of the plate, μ is Poisson's ratio, h is the plate thickness, a is the plate width and L_o is a buckling factor that depends on the ratio of plate width to length. Values of L_o for various aspect ratios may be obtained from figure 3 of Forest Products Laboratory Report No. 1560.⁵

If equation (1) is applied to a single-foil-thick cell wall, it can be shown that, as core thickness increases, L_o decreases and the buckling stress decreases. Thus, the amount of support provided for the cell walls of double-foil thickness decreases as core thickness increases. This may be assumed to be equivalent to increasing the effective width of a simply supported cell wall.

⁵Kuenzi, E. W., and Ericksen, W. S. Shear Stability of Flat Panels of Sandwich Construction, Forest Products Laboratory Report No. 1560, 1960.

Equation (1) was solved by using data averages to determine the effective cell wall widths for each core thickness (table 2). The core stresses were computed from the results of equation (1) by multiplying by $4t/3S$. The actual cell wall width for a 3/8-inch cell is 0.216 inch. Thus, the relatively small changes in effective cell wall width are sufficient to account for the results obtained.

Buckling criteria are not directly applicable to shear in the WT plane, but it is probable that the same factors of edge support and cell wall length to height-ratio control the maximum shear stress. Figure 5 shows that the shear strength decreased 23 percent as core thickness increased from 1/2 inch to 4 inches.

The proportional limit shear stress is probably determined by the stress at which buckling of the single-cell walls occurs. This stress is affected by core thickness as previously explained. Consequently, a decrease in proportional limit stress with increasing core thickness would be expected. This is confirmed by the curves in figure 6, which show a decrease of about 40 percent in proportional limit stress as core thickness increased from 1/2 inch to 4 inches.

Since the core shear modulus depends only on the type and thickness of foil used and core geometry, it would not be expected that the shear modulus would be affected by changes in core thickness. However, the data obtained suggest a marked increase in shear modulus with increasing core thickness (fig. 7). Shear modulus increased about 30 percent as core thickness increased from 1/2 inch to 4 inches. This trend is probably a result of the method used to obtain deformation measurements. Certain systematic errors that are negligible for thin cores may become important for thicker ones. In the evaluation of a 4-inch-thick core, the collar used for measuring deformations had a span of about 5 inches between its fixed end and the point of contact for the dial stem (fig. 3). A clockwise rotation of the collar relative to the dial of about 1.5 minutes at proportional limit stress would reduce the observed deformation by about 0.002 inch. This would increase the apparent shear modulus by 30 percent. Such a rotation might be caused by bending of the plates, relative rotation of the plates under load, or by settlement of the collar from testing machine vibration. Errors of this type would be roughly proportional to core thickness. For design purposes, it is conservative to use the shear modulus for 1/2-inch-thick core to design parts of other thicknesses.

Conclusions

Comparable results may be obtained in shear evaluation of aluminum-honeycomb cores by either tension or compression loading methods.

For the core evaluated (0.0024-foil, 3/8-inch cells), an increase in core thickness from 1/2 inch to 4 inches reduced the shear strength parallel to the core ribbon direction 36 percent, reduced shear strength perpendicular to the core ribbon direction 23 percent, and reduced the proportional limit stress 40 percent.

Table 1.--Shear properties of aluminum honeycomb core¹ of thicknesses ranging from 1/2 inch to 4 inches

Specimen size			Core ribbons parallel to direction of loading (LT)				Core ribbons perpendicular to direction of loading (WT)			
Thickness	Length	Width	Core density	Maximum stress	Proportional limit stress	Shear modulus	Core density	Maximum stress	Proportional limit stress	Shear modulus
In.	In.	In.	Lb. per cu. ft.	P.s.i.	P.s.i.	P.s.i.	Lb. per cu. ft.	P.s.i.	P.s.i.	P.s.i.
PRODUCED BY TENSION LOADING										
1/2	6	2	2.86	188	91	41,500	2.89	97	54	17,200
1/2	6	2	2.93	187	91	38,800	2.89	98	54	17,000
1/2	6	2	2.89	195	116	35,600	2.85	97	58	16,400
1/2	6	2	2.89	187	107	33,400	2.81	95	46	18,200
1/2	6	2	2.89	188	91	40,800	2.89	102	63	17,100
1/2	6	2	2.84	185	92	35,800	2.88	103	37	20,300
Av.			2.88	188	99	37,600	2.87	99	52	17,700
Adjusted Av. ²				188	100	37,900		100	53	17,900
PRODUCED BY COMPRESSION LOADING										
1/2	6	4	2.86	181	98	38,100	2.89	100	58	18,200
1/2	6	4	2.86	179	102	37,700	2.85	100	57	18,700
1/2	6	4	2.86	180	100	37,900	2.86	97	41	18,700
Av.			2.86	182	101	38,400	2.87	99	52	18,500
Adjusted Av. ²				182	101	38,400		100	53	18,700
1	12	4	2.90	164	86	40,700	2.88	93	43	19,800
1	12	4	2.91	159	82	46,000	2.93	97	41	21,200
1	12	4	2.92	162	74	46,000	2.94	96	43	21,200
Av.			2.91	162	81	44,200	2.92	95	42	20,700
Adjusted Av. ²				162	81	44,000		94	42	20,600
2	24	4	2.92	145	72	43,700	2.89	87	37	22,100
2	24	4	2.89	140	62	40,500	2.89	89	39	22,300
2	24	4	2.90	139	57	38,200	2.91	91	37	24,400
Av.			2.90	141	64	40,800	2.90	89	38	22,900
Adjusted Av. ²				141	64	40,800		89	38	22,900
4	48	4	3.15	132	78	56,000	2.89	76	31	23,900
4	48	4	3.15	127	73	54,400	2.91	77	34	24,600
4	48	4	3.18	129	73	52,300	2.90	79	31	25,000
Av.			3.16	129	75	54,200	2.90	77	32	24,500
Adjusted Av. ²				118	69	49,700		77	32	24,500

¹Core of 0.0024-inch, 3003-H19 aluminum foil expanded to 3/8-inch hexagon cells.

²Adjusted for density of 2.90 pounds per cubic foot.

Table 2.--Calculation of shear buckling stresses for cores of
several thicknesses

Core thickness	Effective core thickness	Effective cell wall width	L_0	Core stress
<u>In.</u>	<u>In.</u>	<u>In.</u>		<u>P.s.i.</u>
1/2	0.40	0.25	6.75	185
1	.95	.25	5.60	162
2	1.90	.26	5.43	141
4	3.80	.29	5.39	118

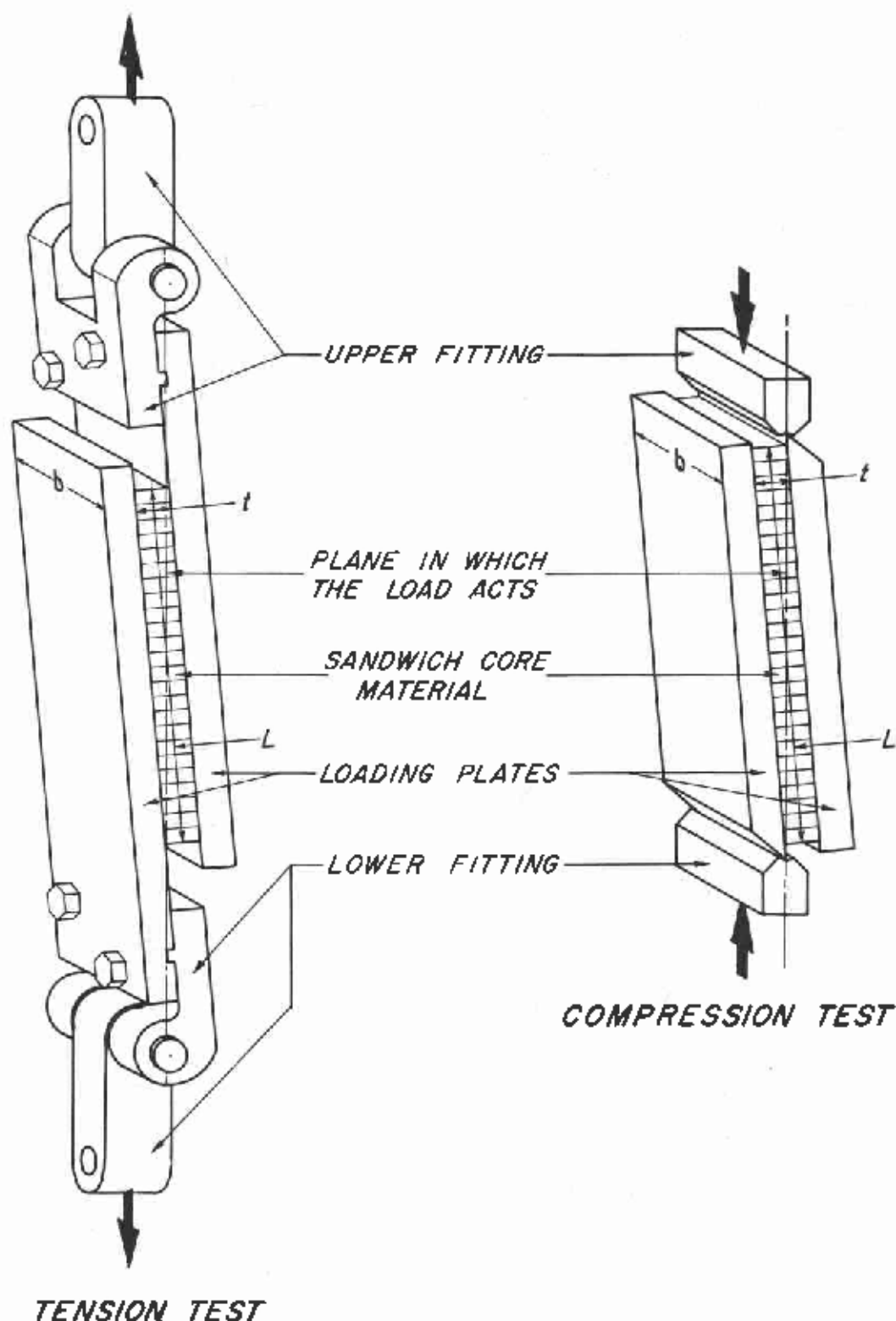


Figure 1.--Sketch showing shear specimens attached to loading plates and plane of action of applied loads.

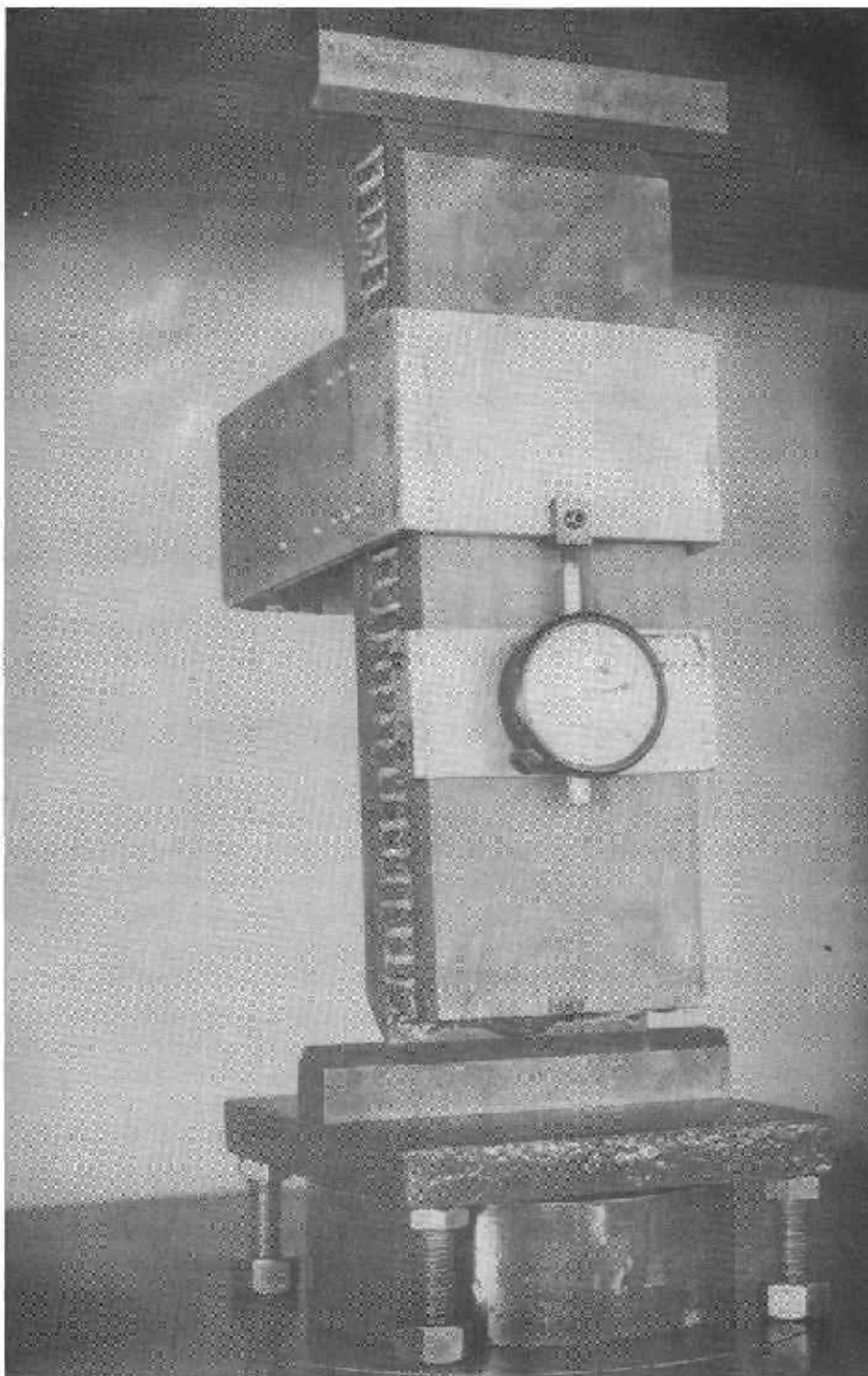


Figure 2. --Apparatus for evaluating core shear properties by compression loading.

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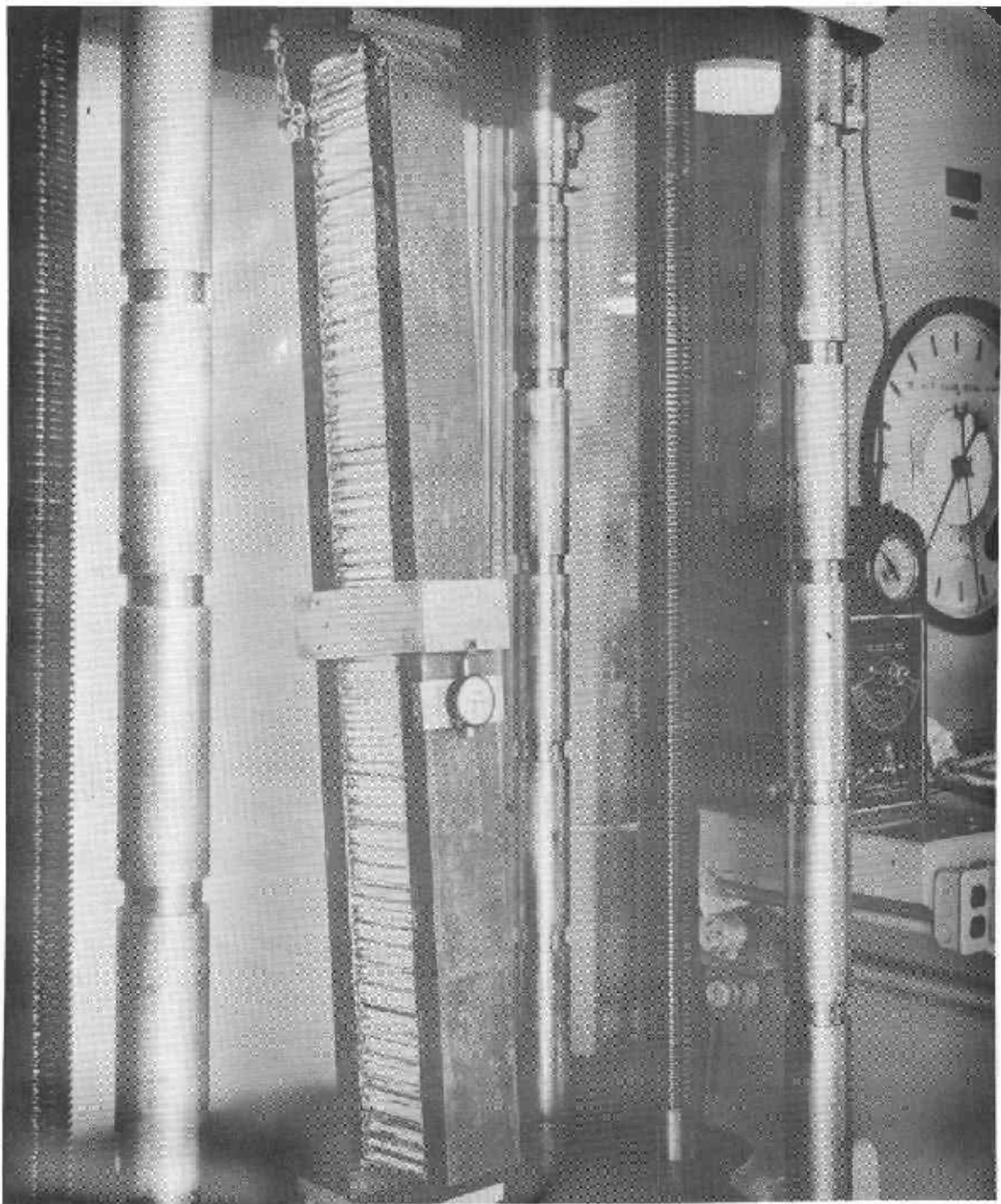


Figure 3.--Specimen and apparatus for evaluating shear properties of larger specimens (2- and 4-inch-thick cores) by compression loading.

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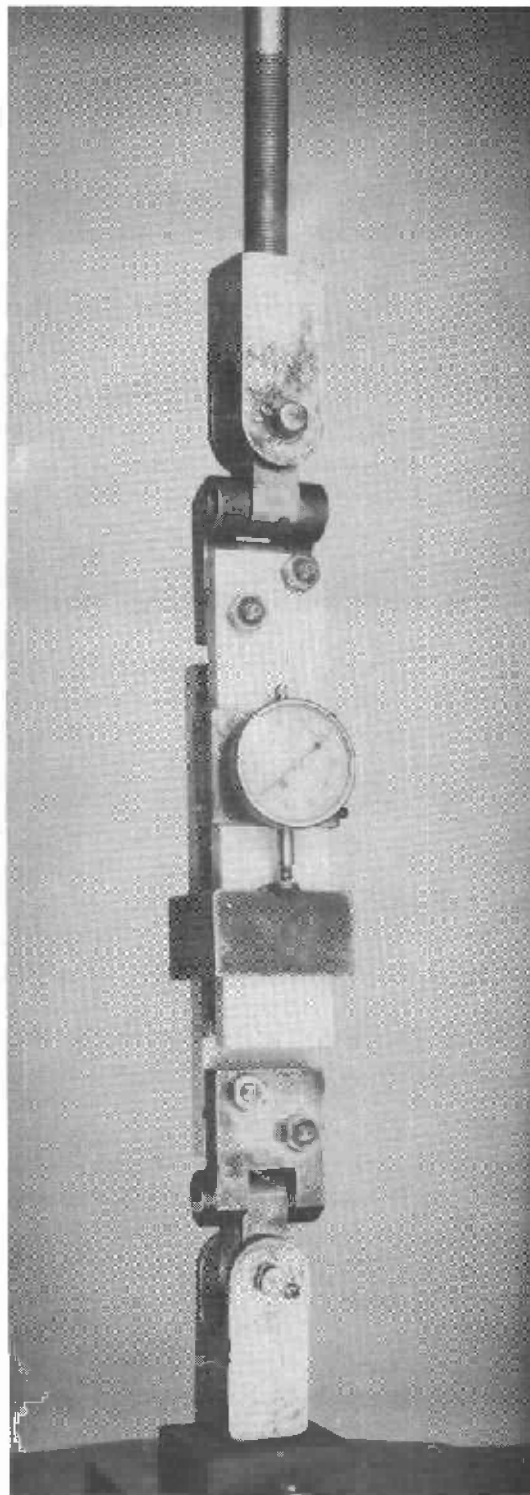


Figure 4. --Apparatus for evaluating core shear properties by tension loading.

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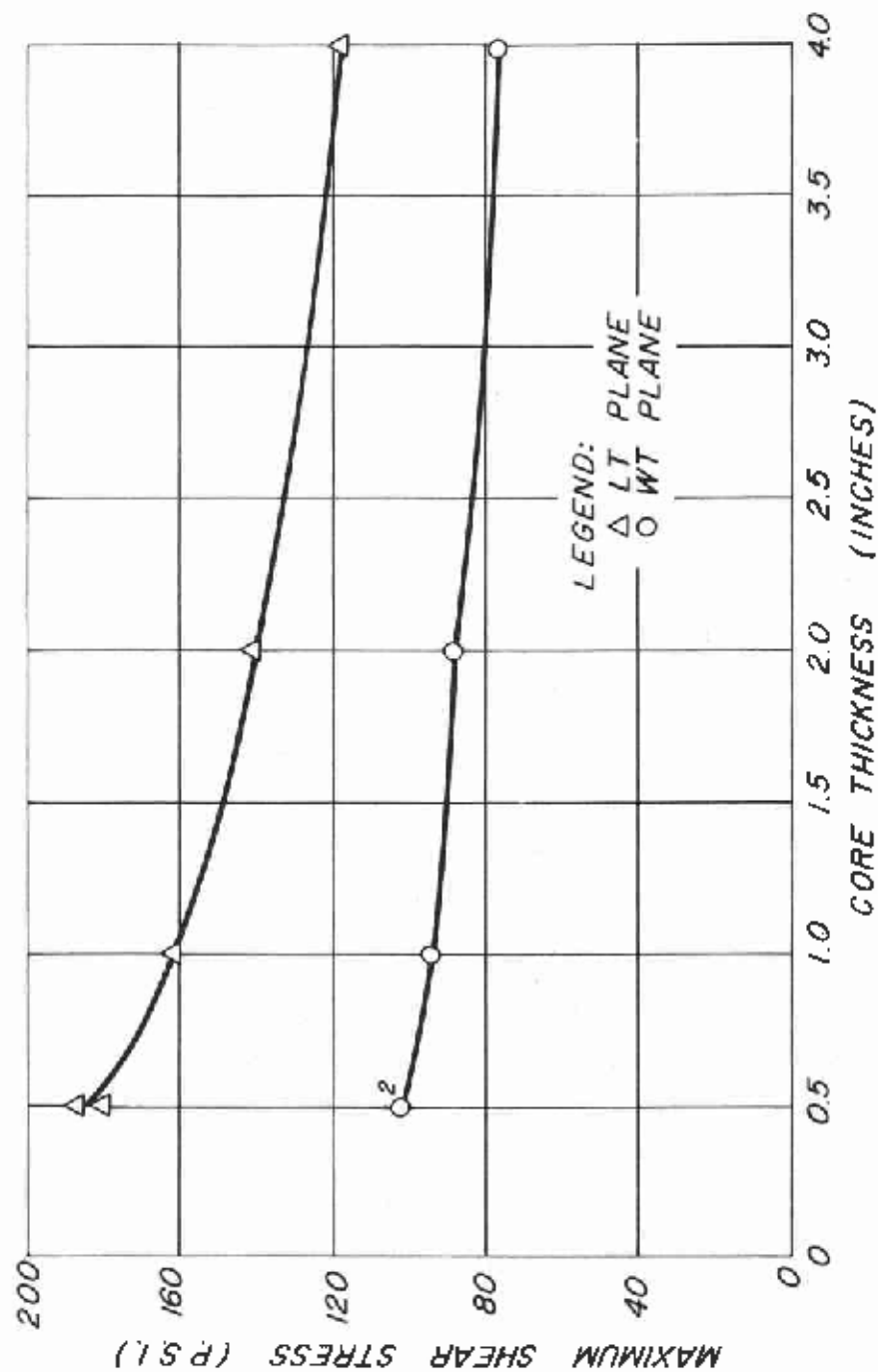


Figure 5. -- Relationship between maximum shear stress and core thickness of aluminum honeycomb core.

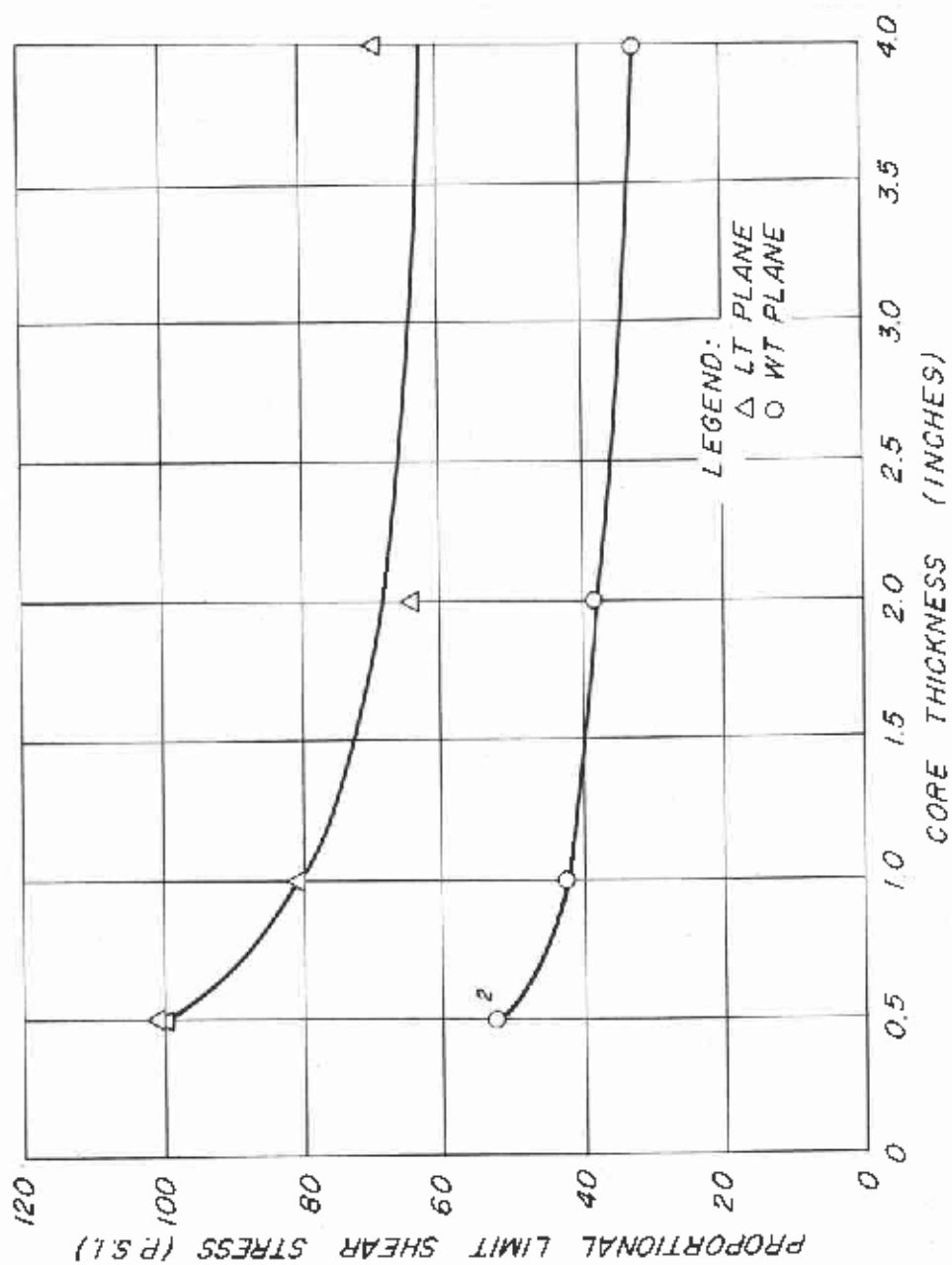


Figure 6. --Relationship between proportional limit shear stress and core thickness of aluminum honeycomb core.

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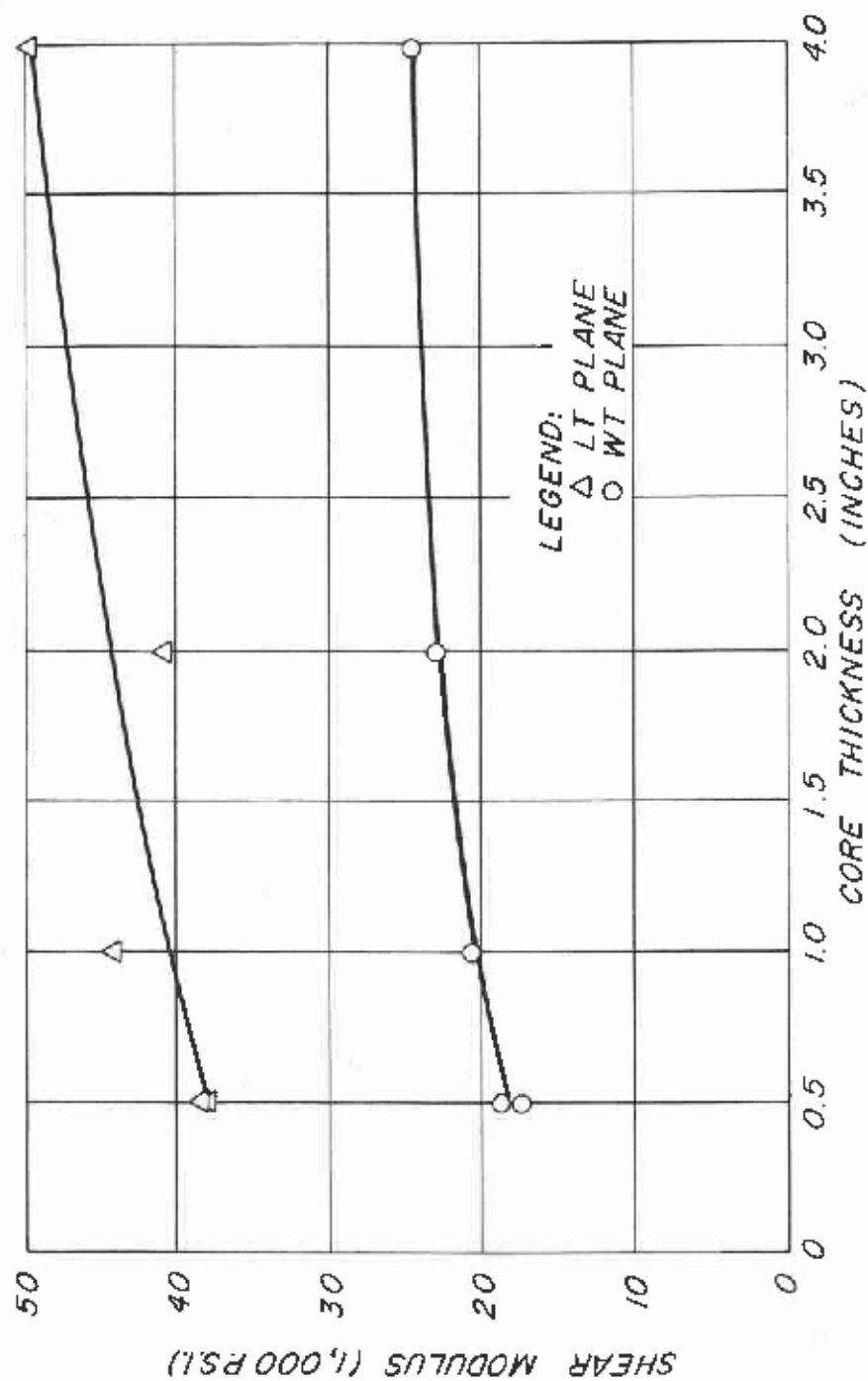


Figure 7.--Relationship between shear modulus and core thickness of aluminum honeycomb core.

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