STRENGTH PROPERTIES OF PLASTIC HONEYCOMB CORE MATERIALS

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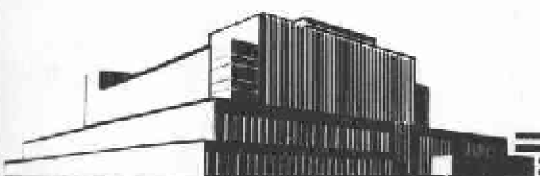

FOREST PRODUCTS LABORATORY
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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

In Cooperation with the University of Wisconsin

STRENGTH PROPERTIES OF PLASTIC HONEYCOMB CORE MATERIALS[1]

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Summary

This report presents the data obtained from the experimental testing of samples of five types of plastic honeycomb core materials for use in sandwich constructions. The materials tested were obtained from commercial sources, and include glass-cloth fabric of 3/8- and 1/4-inch cell sizes, cotton-cloth fabric of 7/16-inch cell size, and paper sheet materials of 7/16- and 1/4-inch cell sizes. Supplementary data obtained from tests made at the Forest Products Laboratory on related projects[3] are given for some of the strength properties of four additional honeycomb cores. Tests were made to determine the basic-strength properties of the materials in compression parallel to the axes of the cells, in tension parallel to the axes of the cells, and in shear in the two planes parallel to the axes of the cells, and to determine Poisson's ratios in two directions perpendicular to the axes of the cells. The strength properties at 65 percent relative humidity and 75° F. were, in general, higher for the cores having the higher specific gravities. On a specific-strength basis (apparent strength ÷ apparent specific gravity) the heaviest core material was not, however, the most efficient of the group. Of the original five core materials tested, the glass-cloth honeycomb cores of 1/4-inch and 3/16-inch cell sizes had the highest specific compressive and tensile strengths, respectively, while the cotton-cloth (4-ounce) honeycomb core of 7/16-inch cell size had the highest specific shear strength. The supplementary data from tests of other 1/4- and 3/16-inch-cell-size glass-cloth material show, however, higher specific shear strengths than that of the cotton honeycomb.

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[1]This progress report is one of a series prepared and distributed by the Forest Products Laboratory under U. S. Navy, Bureau of Aeronautics No. NBA-PO-NAer 00619, Amend. 2, and U. S. Air Force No. USAF-PO-(33-038) 48-41E. Results here reported are preliminary and may be revised as additional data become available.

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

[3]Forest Products Laboratory "Memorandum on Tests of Glass-cloth Honeycomb Cores for Use in Preparation of Specifications." March 1949, to Air Materiel Command, Wright-Patterson Air Force Base.

Introduction

The increase in the demand for core materials of the honeycomb type for use in various sandwich structures has prompted industries to perfect fabrication techniques to the point where a commercial product can be offered to the public. Several honeycomb cores are now on the market for which some information is available on their structure, weight, application, and the like. Before a core material can be correctly utilized and a finished sandwich structure be designed, however, the basic strength properties of the core and of the facing materials must be known. To determine these properties, five plastic honeycomb core materials were obtained from commercial producers of honeycomb products and tested. As additional honeycomb cores become available from other suppliers, they will be similarly tested.

Description of Materials

For identification, each core material has been designated as A, B, C, etc., in the report. All the specimens required for the tests of each core material were cut from a single block of the material as furnished by the manufacturer.

Core A is fabricated from sheets of glass cloth (112-114) that have been impregnated with a polyester resin, cured in a sinusoidal corrugated form, and then bonded together at the crests of the waves with the same polyester resin. The finished core has a 3/8-inch cell, similar to A-flute corrugated core material, and weighs approximately 3.8 pounds per cubic foot.

Core B is made from sheets of 4-ounce cotton sheeting that have been impregnated with a phenolic resin, formed into corrugations having flat rather than curved sides, cured in this form, and then bonded together to, approximately, 7/16-inch hexagonal cells. The material weighs approximately 3.7 pounds per cubic foot.

Core C is similar to core A, but is made with a 1/4-inch cell size, which approximates the B-flute type of corrugated core material, and weighs approximately 6 pounds per cubic foot.

Core D, an experimental material, is a paper-base core having, nominally, 7/16-inch hexagonal cells similar to core B. This material is formed, however, by the expansion method in the following steps: (1) Flat sheets of untreated 70-pound kraft paper (500 sheets, 24 inches by 36 inches) are striped on one side with phenolic glue lines approximately 3/16-inch wide and spaced approximately 1-inch apart, (2) the sheets are laid up in a pack with the stripes in adjacent sheets staggered 1/2 inch, (3) the glue lines are cured in a press, (4) the pack is expanded like an accordion to produce the nominally 7/16-inch cells, and (5) the material is impregnated with a phenolic resin and cured in the expanded form. The completed core weighs approximately 2.4 pounds per cubic foot.

Core E, an experimental material, is similar in form to core C, but is fabricated from a phenolic-resin-impregnated paper that is creped in one direction and crimped in the other in an attempt to give a two-way stretch to the paper. This material has a 1/4-inch cell size and weighs approximately 8 pounds per cubic foot.

Core F is similar to core C, a 1/4-inch cell size glass cloth (112-114) honeycomb core material. This material, however, is slightly heavier than core C, weighing approximately 6.9 pounds per cubic foot. Additional core material was fabricated with 11-ply cross-laminated glass cloth facings making a finished sandwich panel 0.316 inch in thickness.

Core G is similar to core F in form but having a slightly smaller cell size (3/16 inch) and weighing approximately 8.7 pounds per cubic foot. Some of this material was also used as the core of sandwich panels having 11-ply cross-laminated glass cloth facings.

Core H is similar to core B in cell size and shape and is also made from resin-impregnated cotton sheeting. However, the cloth used was heavier producing a core material weighing approximately 5-1/4 pounds per cubic foot.

Core J is made from sheets of 50-pound kraft paper, impregnated with a water-soluble phenolic resin, formed into B-flute corrugations, and treated with a polyester resin that also acts as the bonding agent between the individual sheets. The finished core has an approximately 1/8-inch cell and weighs approximately 6.75 pounds per cubic foot.[4]

Methods of Tests

The procedures followed throughout this testing program conformed to or were similar to the methods described in Forest Products Laboratory Report No. 1555, "Methods of Test for Determining Strength Properties of Core Material for Sandwich Construction at Normal Temperatures," revised March 1948. A new test apparatus was used for the determination of Poisson's ratios.

Compression Tests

Specimens for the compression tests parallel to the axes of the cells (L) of the honeycomb were cut from large blocks of the core material and were approximately 2 by 2 inches in cross section, and were either approximately 6 to 8 inches or 1/2-inch in length. It was necessary, however, to reduce the 8-inch dimensions in some cases, as the amount of material available or the size of the blocks received prevented the cutting of a sufficient number of full-sized specimens. The compression specimens were divided into two equal groups, of which one group was to be tested as cut,

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[4] For additional description see pages 4 and 5, Forest Products Laboratory Report No. 1574, "Fabrication of Lightweight Sandwich Panels of the Aircraft Type."

and the other group was to be tested with the ends of the cell walls of the specimens supported. The ends of the 8-inch specimens were cast in plaster of Paris to a depth of approximately 3/8 inch as shown in figure 1, while the ends of the 1/2-inch specimens were bonded to 11-ply glass cloth facings as an additional support of the bearing surfaces. Load-deformation data to determine the moduli of elasticity of the materials were obtained by means of a 2-inch-gage-length Marten's-mirror compressometer for the 6-to 8-inch specimens and by dial gages between the heads of the testing machine for the 1/2-inch specimens.

Tension Tests

The tension specimens were 1/2 inch in the direction of the axes of the cells (L) and nominally 1 inch in cross section. One-inch aluminum cubes were bonded to the ends of the honeycomb cells (cross-sectional faces), and the specimens were loaded through the cubes in a hydraulic testing machine (fig. 2). Ultimate load, type of failure, and the percentage of core failure were recorded.

Shear Tests

The specimens for the shear tests were 1/2 inch in the direction of the axes of the cells (L) and 2 by 6 inches in cross section. Steel plates were bonded to the ends of the honeycomb cells (cross-sectional faces) in a manner similar to the bonding of facings of a finished sandwich panel. The 6-inch dimension was in the T or R direction as shown by the directional notation in figure 3. The specimens were tested in a hydraulic testing machine, as shown in figure 4, and the deformations were measured by means of a dial gage having 0.001-inch graduations. Load-deformation curves were plotted, from which values of moduli of rigidity were obtained, and the maximum loads and types of failure were recorded. Specimens of cores F and G were tested as sandwich constructions with 11-ply glass cloth facings and approximately 0.316 inch in thickness.

Poisson's-ratio Tests

The specimens tested for the determination of Poisson's ratios were 1/2 inch in the direction of the axes of the cells (L) and 2 by 2 inches in cross section. The test apparatus shown schematically in figure 5 was used for this series of tests, since the apparatus normally used for the testing of wood specimens was not applicable to the testing of honeycomb materials. Poisson's ratios were determined in the TR and RT directions. A specimen, A, figure 5, was placed between the support, B, and the loading bar, C, on 1/8-inch-diameter rollers, so as to permit large deformations to take place within the specimen in the direction of the applied load without appreciable friction between the specimen and the base plate. There was, however, a small amount of friction between the specimen and the rollers as the specimen deformed in the direction perpendicular to that of the load. A wire yoke connected the loading pan, E, and the loading bar, C, and the specimen was loaded by placing the desired number of calibrated weights on the pan. Deformation of the specimen was measured by means of an autocollimated optical-type compressometer of 1-inch-gage length. The specimens were loaded twice in each direction (L and R) , with the deformations being recorded for equal increments of load, in the direction of loading on the first run, and perpendicular to the direction of loading on the second run.

Conditioning of Specimens

All specimens were conditioned to approximate weight equilibrium in a room maintained at 75° F. and 65 percent relative humidity, and were weighed and measured prior to test.

Presentation of Data

Table 1 is a compilation of the mechanical properties of the five commercially fabricated plastic honeycomb core materials as determined from the tests described. Each value in the table under "Compression-test data" is the average of the results of the tests of six specimens. The apparent-specific-gravity data were also determined from the weight and dimensions of the six compression specimens having unsupported or nonplastered ends. Each value under "Tensile-test data" is the average of 10 individual tests, each value under "Shear-test data" is the average of five tests, and each value under "Poisson's-ratio-test data" is the average of two tests. The specific-strength value listed is, in each case, the average apparent strength, as determined from the tests, divided by the apparent specific gravity of the honeycomb, as determined from the weight and the over-all dimensions of the specimens at the time of test.

Table 2 lists data obtained from tests of two additional glass-cloth core materials, similar in cell shape and fabrication to two of the cores of table 1.[3] The compression tests were made on specimens of 1/2-inch length, rather than of 8-inch length as in table 1. The compression specimens having supported ends and the shear specimens were of sandwich construction having 11-ply glass-cloth-base plastic laminated facings.

Table 3 presentssupplementary data on the strength properties of four core materials when tested in the wet and dry conditions. Core materials F and G are the same as reported in table 2 and were 1/2 inch in the direction of the axes of the cells. Cores H and J were tested under another related project[5] and were 6 inches in the direction of the axes of the cells.

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[5]"Durability of Low-density Core Materials and Sandwich Panels of the Aircraft Type as Determined by Laboratory Tests and Exposure to the Weather. Forest Products Laboratory Report No. 1573-B.

Discussion of Results

Core E was the heaviest of the five honeycomb materials listed in table 1, but due to the preparation of the paper sheets prior to fabrication of the honeycomb, it did not have the highest specific-strength properties. The base paper for this core appeared to have been creped in the machine direction of the paper and crimped in the perpendicular direction. This type of base paper can be formed to double-curvature sandwich structures because it can be stretched in two directions. The specific-strength properties in tension, compression, and shear are somewhat reduced, because the crimping of the paper lowers the buckling strength of the individual cell walls. This type of core material may be better suited to absorb shock loads, but no tests have been made in this series to determine the toughness or resilience of the materials. Core E is approximately 30 percent heavier than any of the other cores, and has the greatest apparent compressive and shear strengths, but its tensile strength is lower than that of core C.

Core C, the glass-cloth honeycomb material of 1/4-inch cell size, has the highest specific compressive strength, and core A, the glass-cloth honeycomb material of 3/8-inch cell size, has the highest specific tensile strength. Core B, the 7/16-inch cotton-cloth honeycomb material of 7/16-inch cell size, has, however, considerably higher specific shear strengths than the glass cloth and just slightly more than the plain noncreped paper core, D, of similar cell size. It is recognized that the resin-impregnated glass cloth may have lower shear strengths, as the brittle resin that bonds adjacent fibers spalls off when the material is under high strain and does not support the fibers when stressed in shear. This failure of the resin also occurs in the tension test, but in this case the glass fibers take the full stress after the bond has been broken between fibers, and the effect is not so serious. The tensile strength (and possibly the shear strength) of a core material depends, however, upon the procedures used in fabricating the sandwich structure or test specimens. In compression, the maximum load that a honeycomb specimen can support is dependent upon the buckling strength of the individual cell walls[6], and the resin adds support to the fibers until ultimate failure occurs.

The support given to the ends of the cells of the honeycomb structure by the plaster of Paris is similar to the support that would be found in a sandwich panel in which facings are bonded to the core material. This support, which prevents the ends of the cells from "rolling," increased the compressive strength of the glass-cloth and of the cotton-cloth materials but reduced the strength of the two paper-base core materials. The latter effect may be caused by a loss in strength due to the moisture introduced into the material during the casting process when the plaster of Paris is in the liquid condition. The specimens with plaster bases were not tested until the plaster had set and had been seasoned for a considerable time, and had reached an approximate equilibrium weight in a room maintained at 75° F. and 65 percent relative humidity. The loss in strength of the paper

[6] "An Analysis of the Compressive Strength of Honeycomb Cores for Sandwich Construction," N.A.C.A. Technical Note No. 1251.

cores might not have been experienced if the ends had been supported by some type of resin rather than plaster of Paris.

The values for modulus of elasticity of the glass-cloth cores, as determined from the compression tests, were higher than the values obtained for the cotton-cloth and paper-core materials. This difference again shows the direct correlation between the compressive strength of a honeycomb material and modulus of elasticity, or the buckling strength of the individual cell walls. In every case (table 1) the compressive modulus of elasticity is lower for the specimens having supported ends than for those having free ends. The explanation for these lower values cannot be definitely stated at this time, but they may be due in part to the effect the supported ends have on the compressometer in preventing expansion of the materials due to the effect of Poisson's ratio.

The strength properties are presented in table 2 for the two additional glass-cloth honeycomb core materials, F and G, are considerably different from those given in table 1 for the cores A and C. These differences are due to the sizes of the specimens, methods of test, different density of material, and different shipments for the two groups. For example, the compression strength of core F is larger than core C, but the modulus of elasticity of F is smaller than C. The specimens of core F were one-half inch in the direction of the axes of the cells (L) with deformations measured between the heads of the testing machine, while those of core C were 8 inches long with deformations measured by means of a Marten's mirror compressometer of 2-inch gage length. The method of measuring deformations between the head of a testing machine does not produce values that are a true measure of the modulus of elasticity of the material, because of end effects of the specimen in "rolling" of the end fibers of the cell walls, restraint of Poisson's ratio effect, and the like, which is eliminated by measuring strains over the central portion of a longer specimen. The variation in compressive strengths of these two cores is somewhat accounted for by the higher apparent specific gravity of core F. It is also noted that the appearance of the two core materials was not identical, indicating that perhaps the manufacturer of these two cores had changed the method of cleaning the glass cloth or the type of impregnating resin. The lengths of the two groups of specimens (8 inches for core C and one-half inch for core F) may also partially account for a higher strength of the shorter specimens because of the restraint of the Poisson's ratio effect at the ends of the specimens.

The compressive strength of the honeycomb core materials A and C, table 1, when tested with the ends of the specimens supported in a plaster of Paris cast, would be expected to be lower than the strengths of cores F and G which were tested as sandwich specimens. This difference is partly accounted for by the increase in density of the core from the resin added in bonding on the "wet" laminated glass-cloth facings. The same is true of the values obtained from the shear tests, the cores listed in table 1 were tested as core materials only, while those in table 2 were tested as sandwich material having 11-ply glass-cloth facings.

The strength properties of the five core materials listed in table 1 and of the two additional core materials listed in table 2 were all determined from tests of specimens conditioned in an atmosphere of 75° F. and 65 percent relative humidity. A core may, however, be subjected to higher relative humidities or become saturated with water. Under these latter conditions, the strength properties may be considerably changed and a specific-strength comparison of these core materials may be entirely different. Data obtained from related projects (not the same cores as reported in table 1) show that honeycomb-type core materials may be reduced 50 percent in some strength properties following immersion in water at room temperature for 24 hours. The compressive strength properties of four core materials, tested both wet and dry, are given in table 3. When consideration is given to the strength properties of a completed sandwich structure under moist conditions, methods of fabrication will again partially determine the specific strength of the material.

Design of a sandwich structural element, therefore, cannot be based merely on the strength properties of the separate facing and core materials in the dry condition, but must include the effects of fabrication techniques, and a knowledge of the moisture and temperature conditions to which the finished product will be exposed.

The values obtained from the tests to determine Poisson's ratio are largely dependent upon the form or shape of an individual cell of the honeycomb core material. Cores A, C, and D are made from sheets that have been formed similarly to corrugations and that have a sinusoidal shape. The cell walls are curved sections, and the completed honeycomb cells, including the fillet of glue at the nodal-contact points, are oval. Cores B and D have cell walls that are essentially flat plates, and the cross sections of the full cells are in the form of hexagons. The cotton sheeting used in core B is well formed prior to the final bonding of the sheets to make the finished core, and produces uniform cells throughout the honeycomb. Core D, however, is made by an expansion method by which the adjacent sheets are first bonded together in the flat condition and then the stack of sheets is extended much like an accordion. The resulting honeycomb does not have uniform sizes nor shapes of cells, and the Poisson's ratio determined from the test of one individual specimen may be somewhat different from that obtained from an adjacent specimen cut from the same block.

Poisson's ratios greater than unity were obtained from the tests of several of the cores. It would appear, however, that values greater than unity would not be found for both the RT and TR directions from tests of the same specimen. Considering the low moduli of elasticity in the R and T directions and the small loads applied, the effect of friction between the specimen and the rollers and in the pulley axle may have had some influence on the results obtained from the tests for Poisson's ratio.

Table 1.--Strength properties and dimensions of five plastic honeycomb core materials

Core designation		A	B	C	D	E
Core material		Glass cloth	Cotton cloth	Glass cloth	Paper	Paper
Cell size (nominal)	Inches	3/8	7/16	1/4	7/16	1/4
Apparent specific gravity		0.061	0.059	0.097	0.038	0.128
Compression-test data						
Strength, free ends, (L)	P.s.i.	94	184	193	82	441
Modulus of elasticity, free ends, (L)	P.s.i.	51,500	24,700	82,800	27,400	28,600
Strength, supported ends, (L)	P.s.i.	193	190	366	69	314
Modulus of elasticity, supported ends, (L)	P.s.i.	45,800	23,200	73,800	26,800	27,100
Specific strength, (L)	P.s.i.	3,160	3,220	3,770	2,160	3,420
Tensile-test data						
Strength, (L)	P.s.i.	443	283	640	200	497
Amount of core failure	Percent	7	100	10	77	100
Specific strength, (L)	P.s.i.	7,260	4,800	6,600	5,260	3,850
Shear-test data						
Strength, (LT)	P.s.i.	74	146	172	84	228
Modulus of rigidity (LT)	P.s.i.	6,700	5,600	9,700	7,400	15,500
Specific strength, (LT)	P.s.i.	1,210	2,470	1,770	2,210	1,770
Strength, (LR)	P.s.i.	55	82	46	52	139
Modulus of rigidity, (LR)	P.s.i.	2,440	2,810	2,680	4,670	7,270
Specific strength, (LR)	P.s.i.	900	1,390	470	1,370	1,080
Poisson's-ratio-test data						
Modulus of elasticity (R)	P.s.i.	7.4	11.0	44.6	7.3	136.5
Poisson's ratio (RT)		.35	.49	1.83	2.01	.84
Modulus of elasticity (T)	P.s.i.	17.3	25.4	53.6	14.1	36.5
Poisson's ratio (TR)		.79	1.51	1.26	.10	1.40
Measurements of honeycomb						
Thickness of sheet	Inches	.004	.011	.003	.007	.013
Area per cell	Sq.in.	.12	.18	.05	.17	.06
Wave length	Inches	.70	.86	.44	.44	.44
Wave amplitude	Inches	.35	.46	.22	.85	.25
Length of sheet for 1 wave length	Inches	.82	1.04	.52	1.03	.53

Table 2.--Strength properties of two additional glass-cloth plastic honeycomb core materials[1]

Core designation	F	G
Core material	Glass cloth	Glass cloth
Cell size (nominal)........................ Inches	1/4	3/16
Apparent specific gravity	0.11	0.14
Compression-test data		
Strength, free ends, (L).................... P.s.i.	[2]370	[2]438
Modulus of elasticity, free ends, (L)...... P.s.i.	[2]25,150	[2]21,870
Strength, supported ends, (L).............. P.s.i.	[3]940	[3]1,238
Modulus of elasticity, supported ends, (L). P.s.i.	[3]86,500	[3]135,100
Specific strength, (L)..................... P.s.i.	[2]3,360	[2]3,130
Tensile-test data		
Strength, (L).............................. P.s.i.	[3]388	[3]452
Amount of core failure.................... Percent	0	0
Specific strength, (L)..................... P.s.i.	[3]3,070	[3]3,230
Shear-test data		
Strength, (LT)............................. P.s.i.	[3]352	[3]483
Modulus of rigidity (LT).................. P.s.i.	[3]15,670	[3]24,750
Specific strength (LT).................... P.s.i.	[3]3,200	[3]3,450
Strength, (LR)............................. P.s.i.	[3]186	[3]272
Modulus of rigidity, (LR).................. P.s.i.	[3]9,850	[3]10,780
Specific strength, (LR).................... P.s.i.	[3]1,690	[3]1,940

[1]Data from tests made at the Forest Products Laboratory on a related project in cooperation with the Air Materiel Command, Wright-Patterson Air Force Base.

[2]Length of the specimens parallel to the load — 1/2 inch.

[3]Specimens were of sandwich construction having eleven-ply glass-cloth-base plastic laminated facings.

Table 3.--Strength properties of representative honeycomb core materials in the wet and in the dry conditions[1]

Core designation	F[2]	F[2]	G[2]	G[2]	H[3]	H[3]	J[3]	J[3]
Core material	Glass cloth	Glass cloth	Glass cloth	Glass cloth	Cotton cloth	Cotton cloth	Paper	Paper
Cell size....... Inches	1/4	1/4	3/16	3/16	7/16	7/16	B flute	B flute
Apparent specific gravity (dry)..........	0.11	0.11	0.14	0.14	0.084	0.083	0.104	0.108
Exposure...............	65% R.H.	Wet 24 hr.	65% R.H.	Wet 24 hr.	65% R.H.	Wet 24 hr.	65% R.H.	Wet 24 hr.
Compressive strength (L)............ P.s.i.	370	290	438	274	306	236	559	232
Modulus of elasticity (L)............ P.s.i.	25,150	16,960	21,870	10,190	29,130	19,760	70,670	24,200
Specific strength (L)............ P.s.i.	3,360	2,640	3,130	1,960	3,640	2,810	5,380	2,230

[1] All specimens tested with unsupported ends. Specimens from cores F and G were 1/2 inch long with deformation measured between the heads of the testing machine. Specimens from cores H and J were nominally 6 inches long with deformations measured by means of a Marten's compressometer of 2-inch gage length.

[2] Data from tests made at the Forest Products Laboratory on a related project in cooperation with the Air Materiel Command, Wright-Patterson Air Force Base.

[3] Data to be published in Forest Products Laboratory Report No. 1573-B.

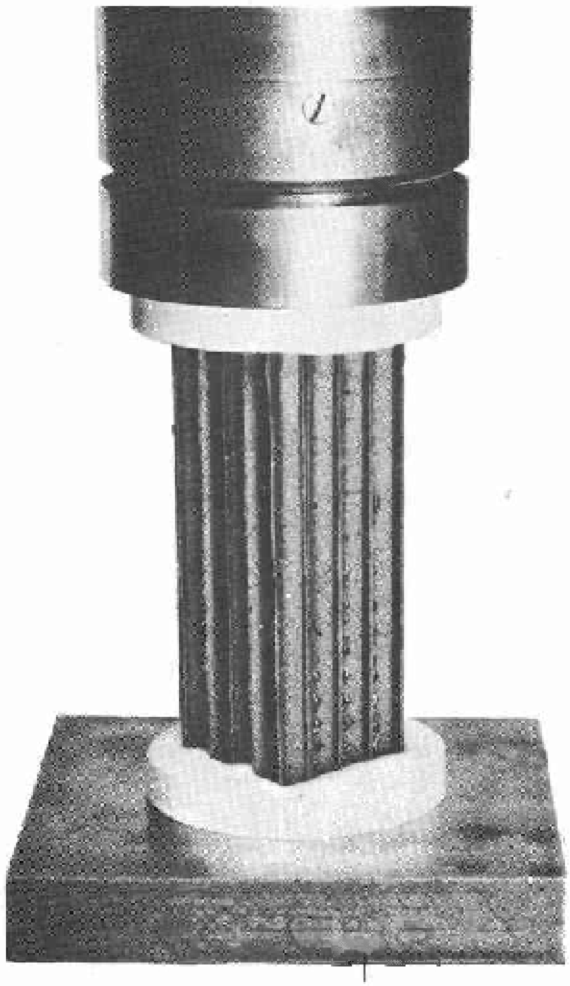

Figure 1.--Compression specimen of honeycomb core material with ends supported by plaster of Paris.

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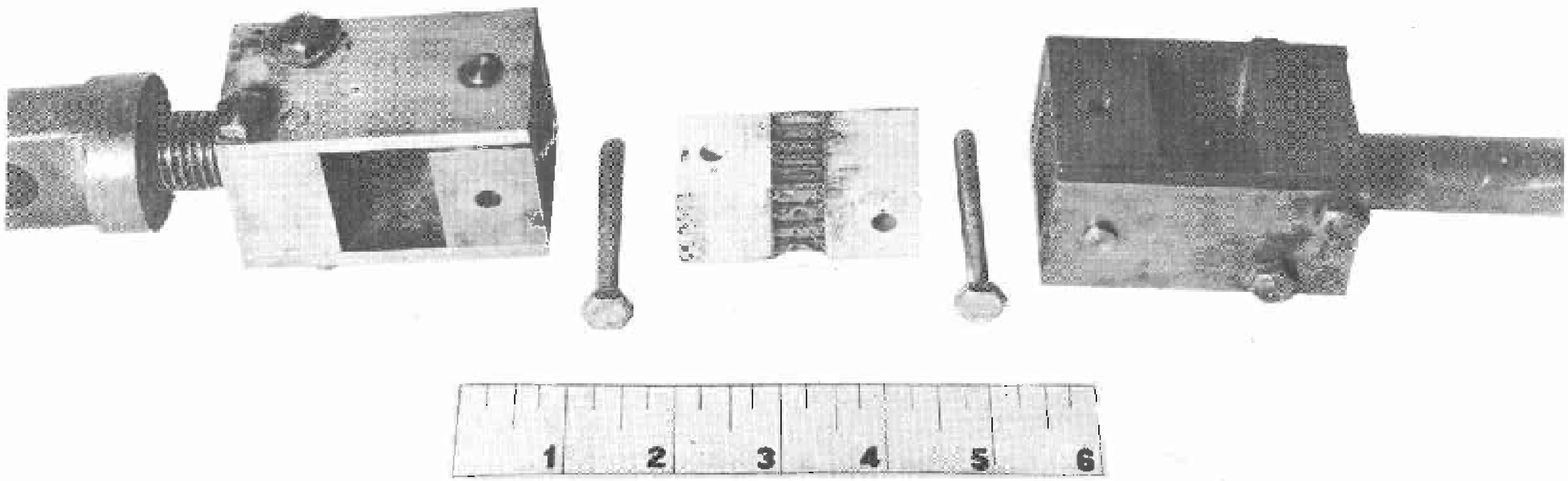

Figure 2.--Tensile-test apparatus of a honeycomb core material showing the aluminum cubes and grips for applying load to the specimen.

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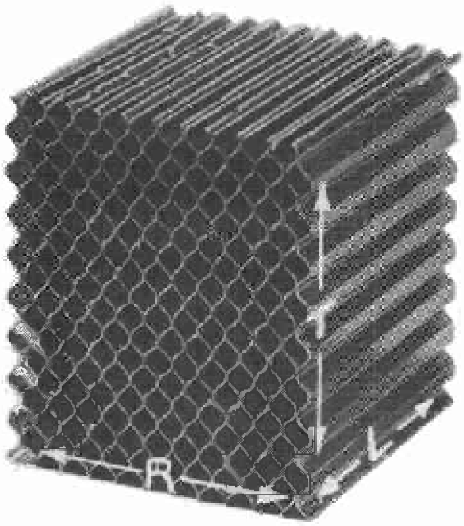

Figure 3.--Cross-sectional view of a honeycomb core material, showing the directional notation as used in this report.

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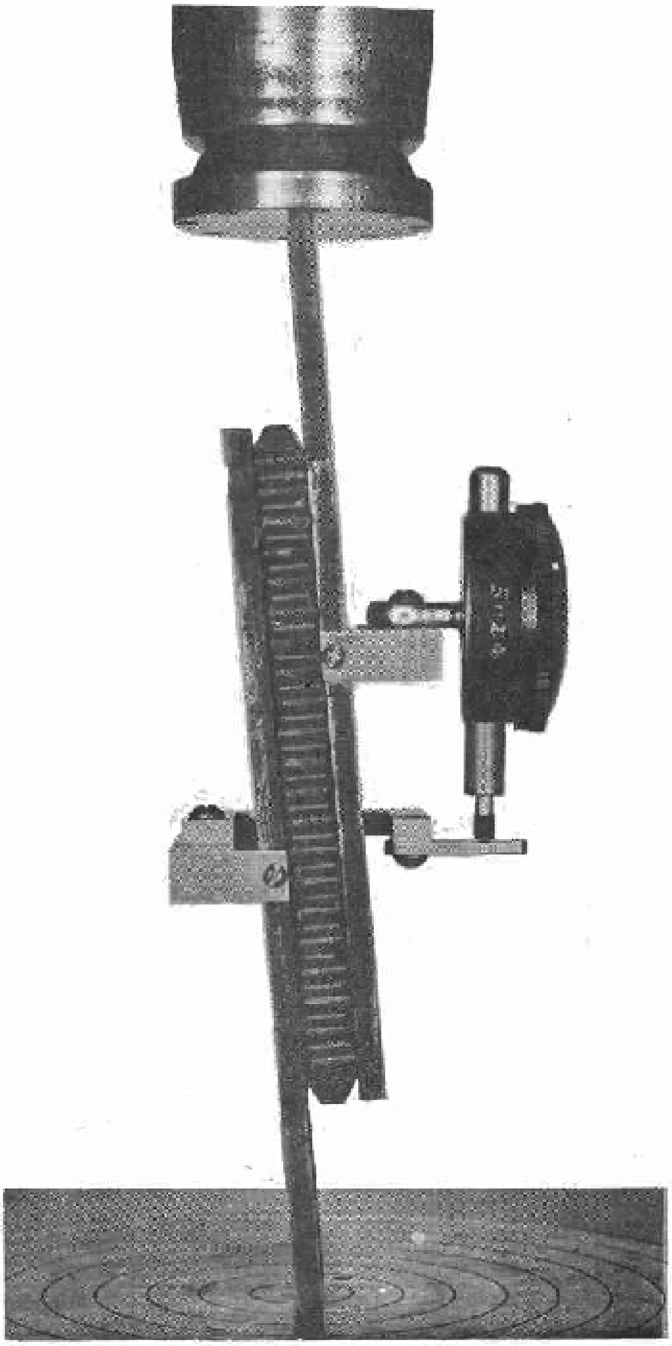

Figure 4.--Shear specimen of honeycomb core material showing apparatus for measuring shear deformations.

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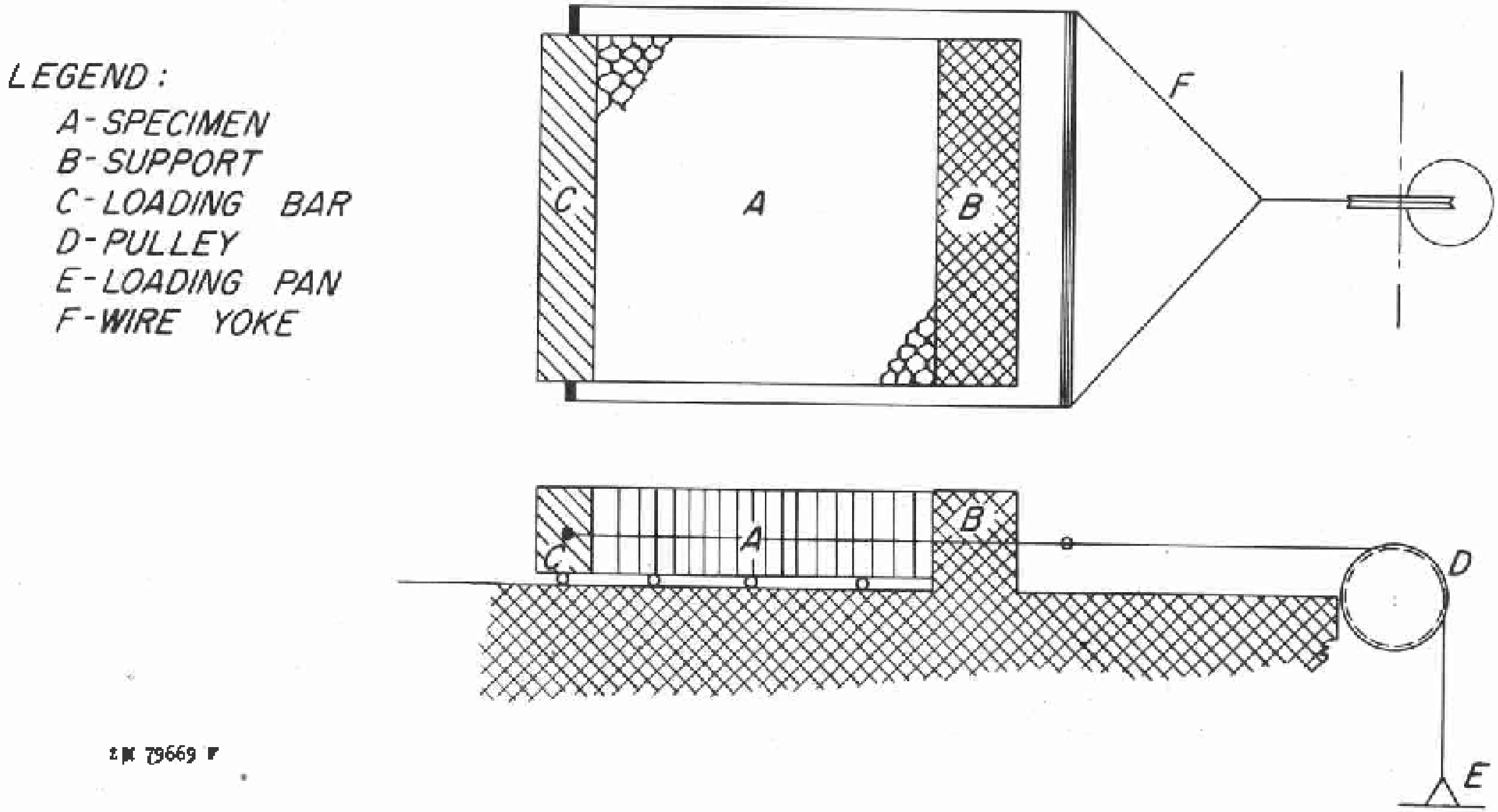

Figure 5.--Schematic diagram of test apparatus for determining Poisson's ratio for 1/2- by 2- by 2-inch honeycomb core specimens.