COMPRESSIVE AND SHEAR PROPERTIES OF POLYAMIDE HONEYCOMB CORE
Abstract

Polyamide honeycomb cores, prepared from resin-treated polyamide paper to densities of 1.5 and 3 p.c.f. (pounds per cubic foot), were evaluated in compression and shear. Properties determined will enable structural engineers to arrive at rational designs of sandwich constructions using these cores.

Compressive strengths at 75°F. were 100 p.s.i. (pounds per square inch) for the 1.5 p.c.f. core and 320 p.s.i. for the 3 p.c.f. core. At 500°F. compressive strengths were 55 percent of those at 75°F. for the 1.5 p.c.f. core and 40 percent for the 3 p.c.f. core.

At 75°F. shear strengths parallel to the core ribbon direction were 60 and 170 p.s.i. for the respective cores, with values of 48 and 95 p.s.i. perpendicular to the core ribbon direction.
COMPRESSIVE AND SHEAR PROPERTIES OF

POLYAMIDE HONEYCOMB CORE

By

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U.S. Department of Agriculture

Introduction

Sandwich constructions comprised of strong thin facings bonded to a thick lightweight core can be used to produce stiff lightweight structural panels for aircraft and other flight vehicles. Sandwich panels with polyamide honeycomb cores have been used for sidewalls, ceilings, and partitions in aircraft interiors and may be utilized for such exterior parts as control surfaces and wing leading and trailing edges where the chemical and physical characteristics of polyamide honeycomb are advantageous.

In use, polyamide honeycomb cores may be subjected to shear and compressive stresses and to aerodynamic heating. The purpose of this study was to evaluate shear properties of polyamide honeycomb core at 95°F and compressive properties at 75°F, 300°F, and 500°F.

The Military Handbook 23 Working Group sponsored this project, and experimental and analytical work was conducted at the Forest Products Laboratory in 1968.

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1 This Note is another report in the series (MIL-HDBK-23) prepared and distributed by the Forest Products Laboratory under U.S. Air Force DO F33615–69–M–5000. Results here are preliminary and may be revised as additional data become available.

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

FPL–0202
Core Materials Used

Honeycomb cores of polyamide ribbons were produced commercially and were received from the manufacturer in sheets of the required thicknesses.

Polyamide core ribbons were produced from a paper made up of polyamide aromatic polymer in the form of short (1/4 in.) straight fibers and smaller fibrous binder particles. The fibers and particles were permanently bonded to each other by heat and pressure during a hot calendering operation to produce a relatively impermeable sheet of 2-mil thickness. The polyamide paper was made into blocks of expanded honeycomb core having 1/8 or 1/4 inch hexagonal cells. These blocks of core were then treated with a heat-resistant phenolic resin to produce cores of the required densities. Sheets of core were then cut from each core block with a bandsaw.

The following core material was supplied by the manufacturer:
(1) Ten sheets of 1/2-inch-thick core (1/8 in. cells, nominal 3 p.c.f.) sampled from different production runs.
(2) Three sheets of 1/2-inch-thick core (1/4 in. cells, nominal 1.5 p.c.f.) sampled from different production runs.
(3) One sheet, 1 inch thick, of each type of core.

Preparation of Specimens

Core received from the manufacturer was conditioned to constant weight in a room maintained at 73° F. and 50 percent relative humidity. Then, each sheet of core was weighed and measured and the density calculated. Specimens were cut from the sheets of core using a bandsaw.

Compression Specimens

Compression specimens were 4 inches square and 1/2 or 1 inch thick. Six specimens, for determination of stress-strain data and maximum stress, were cut from each of the two sheets of 1-inch-thick core for each of the test temperatures (75°, 300°, and 500° F.). Because only one block was represented at each core density, it was desirable to obtain additional information about the variability in compressive properties of cores from different blocks. Therefore, compression specimens, for maximum load test only, were cut from the sheets of 1/2-inch core.
One specimen for each test temperature was cut each of the 10 sheets of 3 p.c.f. density, 1/2-inch-thick core. Two 1/2-inch-thick compression specimens were cut from each of the three sheets of 1.5 p.c.f. core for each test temperature.

Ends of the compression specimens to be tested at 75° and 300° F. were dipped in a room-temperature-setting epoxy resin to form reinforcing fillets about 1/16 inch deep at each end of the core cells. Ends of specimens to be tested at 560° F. were dipped in a refractory cement to form reinforcing fillets 1/16 to 1/8 inch deep.

Specimens were conditioned in a room maintained at 73° F. and 50 percent relative humidity. They were removed from the conditioning room and tested immediately.

Shear Specimens

Shear specimens; were 4 inches wide, 6 inches long, and 1/2 inch thick. Pairs of specimens were cut from each sheet of core. One specimen had the core ribbon direction parallel to the 6-inch length and the other had the ribbon direction parallel to the 4-inch width. One pair of specimens were cut from each of the 10 sheets of 3 p.c.f. core, and two pairs of specimens were cut from each of the three sheets of 1.5 p.c.f. core.

Steel loading plates 3/4 inch thick were bonded to the core with a room-temperature-setting epoxy resin (fig. 1). The loading plates were stiff enough to resist bending. A stiffness of at least 600,000 lb-in² for each inch of width and inch of core thickness is recommended. The plates used were 50 percent thicker than required to provide this recommended minimum stiffness. The core cell ends contacted the loading plates and the resin formed fillets, which bonded the cell walls to the plates.

Specimens were stored in a room maintained at 73° F. and 50 percent relative humidity until the adhesive had cured. They were removed from the room and tested immediately.

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Figure 1.--Core shear apparatus showing specimen with attached loading plates, spherical bearing block, and dial gage assembly used for measuring deformations.

M 134 889

Figure 2.--Core compression apparatus showing specimen, magnesium loading plates, movable bearing block, and heating oven.

M 134 888
Evaluation of Specimens

Compression Specimens

Compression specimens were mounted between two loading plates, and this assembly was placed between a bearing block and the upper platen of a testing machine as shown in figure 2. The bearing block was free to rotate about two mutually perpendicular horizontal rods to permit alinement of the specimen. The loading plates were of magnesium alloy tooling plate 4-1/2 inches square by 1/2 inch thick. These plates were chosen because their flatness and thickness are held to very close tolerances in manufacture. In order to conduct tests at elevated temperatures, the loading apparatus was enclosed in an oven. Testing machine platen extensions passed through holes in the top and bottom of the oven. Platen extensions, the bearing block assembly, and metal parts of the compressometers were made of stainless steel.

A load of 50 to 200 pounds was applied while the specimens were alined. Screw jacks were then placed under each corner of the bearing block to prevent further movement of the block. Load was then applied at a rate such that failure occurred in 3 to 6 minutes. Specimens failed by progressive buckling of the cell walls, followed by crushing and crinkling of the cell corners.

Specimens tested at 300° and 500° F. were alined and the screw jacks positioned before closing the oven door. The alinement load was maintained while the specimens were heated. Specimens were heated until the interior of the specimen reached test temperature and then loaded to failure.

Load-deformation data were obtained for the 1-inch-thick specimens. Marten's mirror compressometers were mounted on the loading plates prior to placing the specimen in the oven. The specimen and loading plate assembly were initially held together by a pair of small springs mounted on pins on opposite sides of the loading plates (fig. 2). The lower loading plate had a shallow groove on both the front and rear edges to position the fixed knife edges of the compressometers. The front and rear edges of the upper loading plate were machined with closely spaced horizontal grooves to provide a nonslip surface for mounting the movable knife edges of the compressometers. After the specimen had been alined in the testing machine, the springs were removed. For elevated temperature tests, the optical paths of the Marten's mirror compressometers passed through a window at the front of the oven.
Table 1. -- Compressive properties of 1-inch-thick polyamide honeycomb core

<table>
<thead>
<tr>
<th>Test temperature</th>
<th>1.5 p.c.f. core</th>
<th>3 p.c.f. core</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum stress</td>
<td>Proportional limit stress</td>
</tr>
<tr>
<td>°F.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
</tr>
<tr>
<td>75</td>
<td>99</td>
<td>56</td>
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<td></td>
<td>99</td>
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<td>56</td>
</tr>
<tr>
<td></td>
<td>96</td>
<td>56</td>
</tr>
<tr>
<td>Av.</td>
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<td>57</td>
</tr>
<tr>
<td>S.D.</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>300</td>
<td>74</td>
<td>44</td>
</tr>
<tr>
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<td>S.D.</td>
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<tr>
<td>500</td>
<td>54</td>
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<td>19</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>19</td>
</tr>
<tr>
<td>Av.</td>
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<td>20</td>
</tr>
<tr>
<td>S.D.</td>
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<td>4</td>
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</tbody>
</table>

1-2 mil polyamide paper formed to 1/4-inch hexagonal cells.

2-2 mil polyamide paper formed to 1/8-inch hexagonal cells.
Shear Specimens

Shear specimens were evaluated using the apparatus shown in figure 1. The specimens, with attached loading plates, were mounted between notched blocks between the platens of a testing machine, with the lower end supported on a spherical bearing block. An initial load of 50 to 100 pounds was applied while the loading plates were firmly and evenly seated in the notched blocks by tapping the spherical bearing blocks with a hammer. Screw jacks were then placed under the four corners of the spherical bearing block (fig. 1) to prevent further movement of the block during application of load. The movable platen of the testing machine was driven at a constant speed such that 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, as shown in figure 1. The steel collar was attached to one loading plate with set screws, while the dial gage was similarly fastened to the other 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.

Presentation of Data and Discussion of Results

Core Density

Average densities of the sheets of core used for 1-inch-thick compression specimens were 1.57 and 3.00 p.c.f. The 10 sheets of 1/2-inch-thick core having 1/8-inch cells had an average density of 2.86 p.c.f. and a standard deviation of 0.13 p.c.f. The three sheets of 1/2-inch-thick core having 1/4-inch cells had an average density of 1.46 p.c.f. and a standard deviation of 0.08 p.c.f.

Core Compressive Properties

Compressive properties of 1-inch-thick polyamide honeycomb core are given in table 1. Properties of individual specimens, average values, and standard deviations are given for each core density and test temperature. Core density and compressive strength values for 1/2-inch-thick specimens are presented in table 2.
Table 2.--Compressive strength of 1/2-inch-thick polyamide honeycomb core

<table>
<thead>
<tr>
<th>Test temperature</th>
<th>Nominal 1.5 p.c.f. core</th>
<th>Nominal 3 p.c.f. core</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Actual core density</td>
<td>Maximum compressive stress</td>
</tr>
<tr>
<td>°F.</td>
<td>P.c.f.</td>
<td>P.s.i.</td>
</tr>
<tr>
<td>75</td>
<td>1.53</td>
<td>113</td>
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<tr>
<td></td>
<td>1.53</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Av.</td>
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<tr>
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<td>S.D.</td>
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<td>10</td>
</tr>
<tr>
<td>500</td>
<td>1.53</td>
<td>46</td>
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<tr>
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<td>1.48</td>
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<tr>
<td>Av.</td>
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</tr>
<tr>
<td>S.D.</td>
<td>0.08</td>
<td>6</td>
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</table>

1-2-mil paper formed to 1/4-inch hexagonal cells.
2-2-mil paper formed to 1/8-inch hexagonal cells.
The effect of test temperature on the flatwise compressive strength of polyamide cores is shown in figure 3. Compressive strengths at 500°F. were 55 percent of 75°F. values for the 1-5 p.c.f. core, and 40 percent for the 3 p.c.f. core.

The 3.63 p.c.f. core had about three times the compressive strength of the 1.5 p.c.f. core at all test temperatures. On the basis of density alone it would be expected that the heavier core would be about twice as strong as the lighter one. An improved strength/density ratio for the 3 p.c.f. core is probably a result of the fact that the smaller cell size increases the buckling strength of the cell walls. The buckling load per unit width is directly proportional to cell wall bending stiffness and inversely proportional to the square of the cell size. On this basis the elastic buckling load of the cell walls of 1/8-inch cells would be four times that of 1/4-inch cells, because the cell wall thicknesses (and hence flexural stiffnesses) are the same. Since the cross-sectional area of the cell walls per square inch of core is twice as much for the 1/8-inch cell size as the 1/4-inch cell size, a 3 p.c.f. core would have an elastic buckling stress eight times that of a 1.5 p.c.f. core. The actual buckling stress is less because the stresses are above the proportional limit and the effective modulus of elasticity; hence, the flexural stiffness is reduced more for the more highly stressed core (3 p.c.f.) than for the less highly stressed core (1.5 p.c.f.).

Maximum stresses for the 1/2-inch-thick cores were not significantly different than those for the 1-inch-thick cores. This might be expected from the range of ratios of cell wall width to height.

There was considerably more variation in compressive strength of specimens from different core blocks than for specimens from the same core block. For the 1.5 p.c.f. core, the coefficient of variation (standard deviation expressed as a percentage of the average value) for compressive strength of 1/2-inch-thick core was 14 percent, compared to 2 to 5 percent for the single block of 1-inch-thick core. For the 3 p.c.f. core, the compressive strength coefficient of variation of the 1/2-inch-thick core was 8 to 13 percent compared to 1 to 4 percent for the single block of 1-inch-thick core. Density coefficient of variation for the 1/2-inch-thick core blocks was 5 percent.

The effect of test temperature on the core compressive modulus of elasticity is shown in figure 4. The ratio of modulus of elasticity of the 3 p.c.f. core to that of the 1.5 p.c.f. core is 2.3 at 75°F., 2.0 at 300°F., and 1.5 at 500°F. The average ratio is 1.9, which agrees with the ratio of core densities.
Figure 3.--Effect of test temperature on flatwise compressive strength of polyamide honeycomb core of two densities and thicknesses.

Figure 4.--Effect of test temperature on compressive modulus of elasticity of polyamide honeycomb core of two densities.
Figure 5.--Typical compressive stress-strain curves for two densities of polyamide honeycomb core at three temperatures.

Figure 6.--Typical shear stress-strain curves for polyamide honeycomb core with load applied parallel and perpendicular to the core ribbon direction.
Table 3.--Shear properties of 1/2-inch-thick polyamide honeycomb core at 75° F.

<table>
<thead>
<tr>
<th>Core loaded parallel to core ribbon direction</th>
<th>Core loaded perpendicular to core ribbon direction</th>
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</thead>
<tbody>
<tr>
<td>Maximum stress</td>
<td>Maximum stress</td>
</tr>
<tr>
<td>Proportional limit stress</td>
<td>Proportional limit stress</td>
</tr>
<tr>
<td>Modulus of rigidity</td>
<td>Modulus of rigidity</td>
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</table>

<table>
<thead>
<tr>
<th>P.s.i.</th>
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<td>60</td>
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<td>15</td>
<td>2,670</td>
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Av. 61  18  2,820  40  10  1,610

S.D. 7  2  310  3  2  80

1.5 P.C.F. CORE

<table>
<thead>
<tr>
<th>3 P.C.F. CORE</th>
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</tr>
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<td>171</td>
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Av. 170  86  6,130  94  42  2,990

S.D. 13  10  680  8  5  330

1/2-mil paper formed to 1/4-inch hexagonal cells.
22-mil paper formed to 1/8-inch hexagonal cells.
The modulus of elasticity at 500° F. was 39 and 58 percent of the 75° F. value for the 3 and 1.5 p.c.f. core, respectively. This difference in the variation in the elastic modulus with temperature may be a result of variations in the thickness and density of the polyamide paper used to make the blocks of core, and in the amount of phenolic resin added to produce core blocks of the required density.

Typical compressive stress–strain curves are shown in figure 5. As the temperature increased: compressive strength, proportional limit stress, and modulus of elasticity decreased, while the strain to failure increased. Failure of the 3 p.c.f. core was quite abrupt, particularly at 75° and 300° F. Failure of the 1.5 p.c.f. core was more gradual, as shown by the nearly horizontal portions of the stress–strain curves. Strain to failure was greater for the 3 p.c.f. core than for the 1.5 p.c.f. core, at all temperatures.

Core Shear Properties

Shear properties of polyamide honeycomb core are presented in table 3. Properties of individual specimens are given as well as averages and standard deviations for each core density and direction of loading. Shear strengths of cores loaded parallel to the core ribbon direction were 1.5 and 11.8 times those of cores loaded perpendicular to that direction for the 1.5 and 3 p.c.f. cores, respectively. Shear strength for the 3 p.c.f. core was 2.8 and 2.4 times that for the 1.5 p.c.f. core in the parallel and perpendicular loading directions, respectively. A ratio of 2.0 might be expected on the basis of core density alone. An improved strength/density ratio for the 3 p.c.f. core might be expected for the reasons discussed for the core compression specimens.

The modulus of rigidity of the 3 p.c.f. core was about twice that for the 1.5 p.c.f. core for both loading directions, as would be expected on the basis of the core density ratio. The moduli of rigidity for core loaded perpendicular to the ribbon direction were 57 and 49 percent of those for core loaded parallel to the core ribbon direction for 1.5 and 3 p.c.f. core, respectively.

Core shear strength coefficients of variation were 7 to 11 percent. The coefficient of variation for core density was 5 percent.

Typical shear stress–strain curves are shown in figure 6. Strain to failure was about 1.6 times as much for cores loaded perpendicular to the core ribbon direction than for cores loaded parallel to the core ribbon direction. Strains to failure were slightly greater for the 3 p.c.f. core as for the 1.5 p.c.f. core for both loading directions.
Summary of Results

Cores evaluated were of 0.002-inch polyamide paper treated with phenolic resin in 1/4- and 1/8-inch hexagonal cell sizes, having nominal densities of 1.5 and 3 p.c.f., respectively.

The 3 p.c.f. core had about three times the compressive strength and twice the modulus of elasticity of the 1.5 p.c.f. core at all test temperatures. Compressive strengths at 75° F. were 100 p.s.i. for the 1.5 p.c.f. core and 320 p.s.i. for the 3 p.c.f. core. Compressive strengths at 500° F. were 55 and 40 percent of 75° F. values for the 1.5 and 3 p.c.f. cores, respectively. Maximum stresses were about the same for 1/2- and 1-inch-thick cores.

Strengths for cores sheared parallel to the core ribbon direction were 60 and 170 p.s.i. for the two cores; for those sheared perpendicular to the core ribbon direction, values were 40 and 95 p.s.i. The modulus of rigidity of the 3 p.c.f. core was about twice that of the 1.5 p.c.f. core. The modulus of rigidity for cores loaded perpendicular to the ribbon direction was about half that for cores loaded parallel.
The FOREST SERVICE of the U.S. DEPARTMENT OF AGRICULTURE is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives - as directed by Congress - to provide increasingly greater service to a growing Nation.