HexWeb™ Honeycomb Attributes and Properties

A comprehensive guide to standard Hexcel honeycomb materials, configurations, and mechanical properties

HEXCEL® Composites

HexWeb Honeycomb Attributes and Properties

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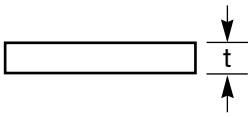
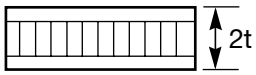
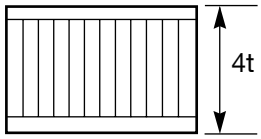
Introduction

Hexcel has produced more than 700 varieties of honeycomb over the past 50 years. Today, HexWeb honeycomb is available in a wide range of materials and cell configurations, and additional products are continually developed in response to new uses for honeycomb sandwich construction.

This brochure lists the materials, configurations, and mechanical properties of Hexcel's standard honeycomb as a guide to selecting honeycomb core best suited for particular applications.

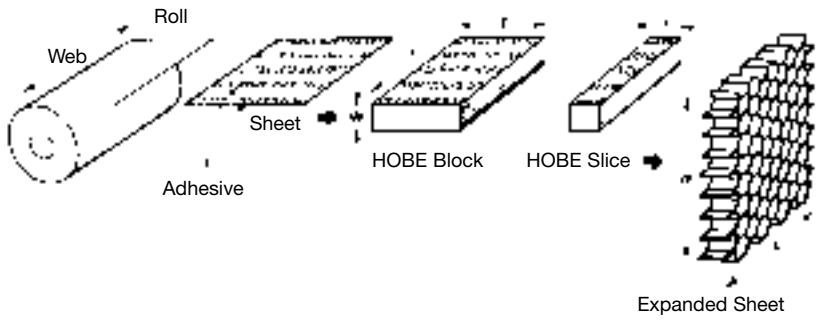
	Solid Metal Sheet 	Sandwich Construction 	Thicker Sandwich 
Relative Stiffness	100	700 7 times more rigid	3700 37 times more rigid!
Relative Strength	100	350 3.5 times as strong	925 9.25 times as strong!
Relative Weight	100	103 3% increase in weight	106 6% increase in weight

A striking example of how honeycomb stiffens a structure without materially increasing its weight.

How Honeycomb Is Manufactured

Honeycomb is made primarily by the expansion method. The corrugated process is most common for high density honeycomb materials.

Expansion Process of Honeycomb Manufacture



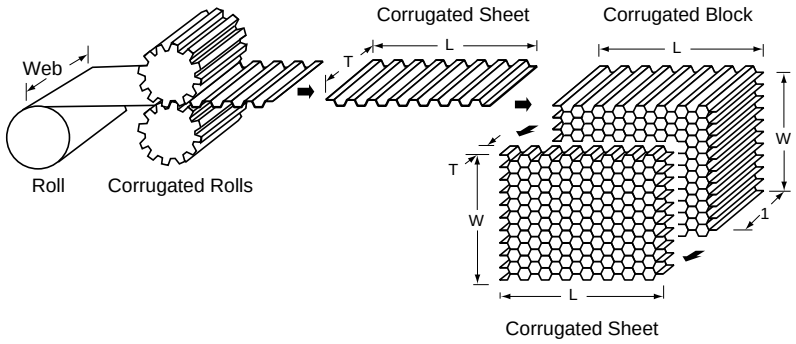
Expansion Process

The honeycomb fabrication process by the expansion method begins with the stacking of sheets of the substrate material on which adhesive node lines have been printed. The adhesive lines are then cured to form a HOBE® (HOneycomb Before Expansion) block.

The HOBE block itself may be expanded after curing to give an expanded block. Slices of the expanded block may then be cut to the desired T dimension. Alternately, HOBE slices can be cut from the HOBE block to the appropriate T dimension and subsequently expanded. Slices can be expanded to regular hexagons, underexpanded to 6-sided diamonds, and overexpanded to nearly rectangular cells.

The expanded sheets are trimmed to the desired L dimension (ribbon direction) and W dimension (transverse to the ribbon).

Corrugated Process of Honeycomb Manufacture



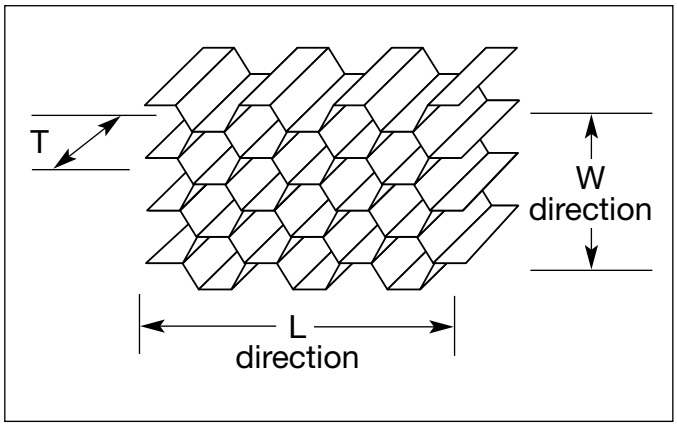
Corrugated Process

The corrugated process of honeycomb manufacture is normally used to produce products in the higher density range. In this process adhesive is applied to the corrugated nodes, the corrugated sheets are stacked into blocks, the node adhesive cured, and sheets are cut from these blocks to the required core thickness.

Honeycomb Cell Configurations

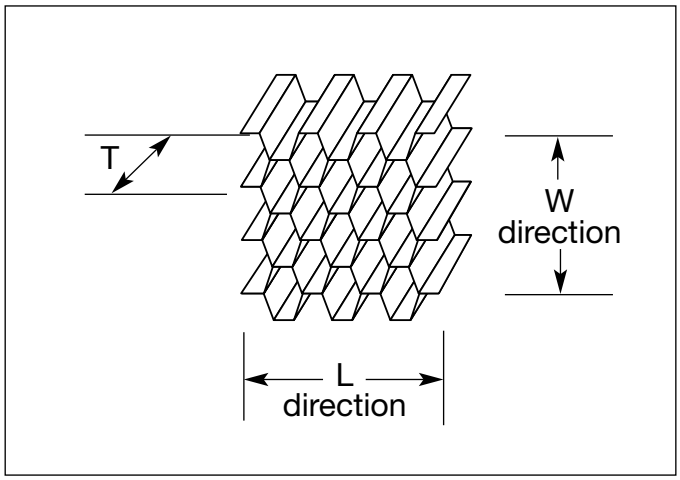
Hexagonal Core

The standard hexagonal honeycomb is the basic and most common cellular honeycomb configuration, and is currently available in all metallic and nonmetallic materials.



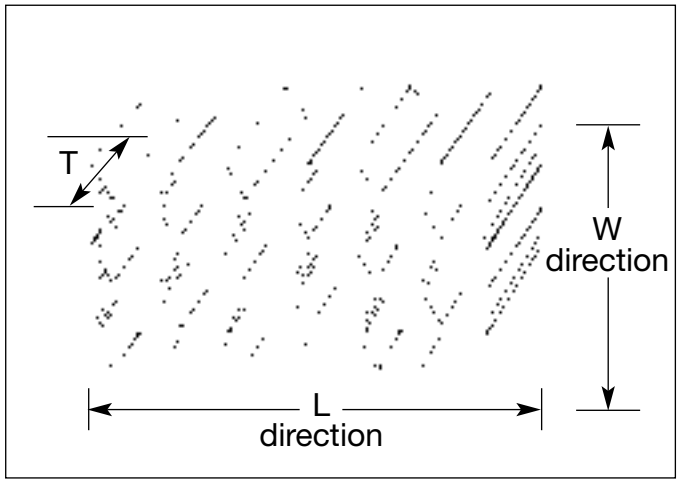
OX-Core™

The OX configuration is a hexagonal honeycomb that has been overexpanded in the W direction, providing a rectangular cell configuration that facilitates curving or forming in the L direction. The OX process increases W shear properties and decreases L shear properties when compared to hexagonal honeycomb.



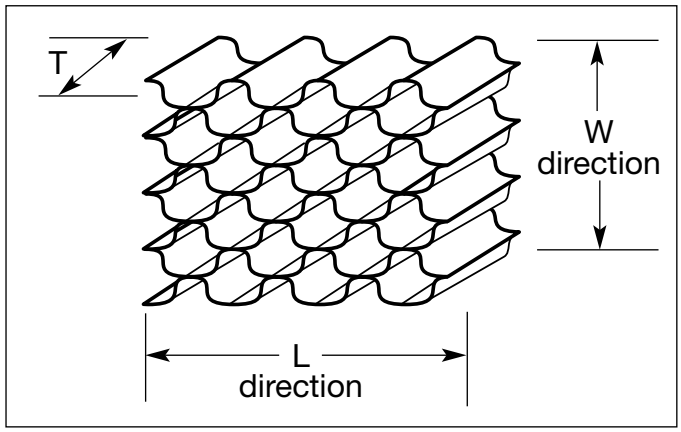
Reinforced Hexagonal Core

Reinforced honeycomb has a sheet of substrate material placed along the nodes in the ribbon direction to increase the mechanical properties.



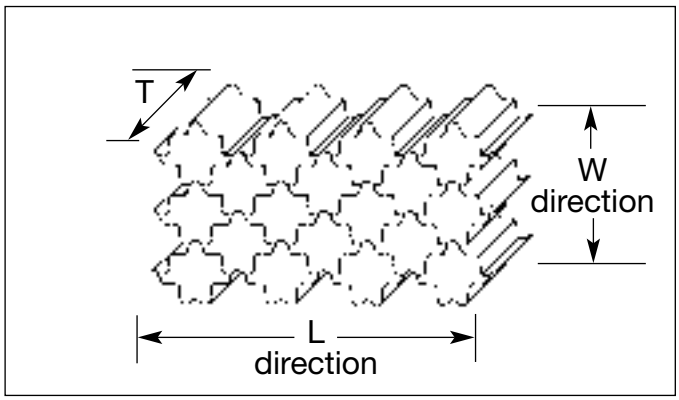
Flex-Core®

The Flex-Core cell configuration provides for exceptional formability in compound curvatures with reduced anticlastic curvature and without buckling the cell walls. Curvatures of very tight radii are easily formed. When formed into tight radii, Flex-Core provides higher shear strengths than comparable hexagonal core of equivalent density. Flex-Core is manufactured from aluminum, Nomex®, and fiberglass substrates.



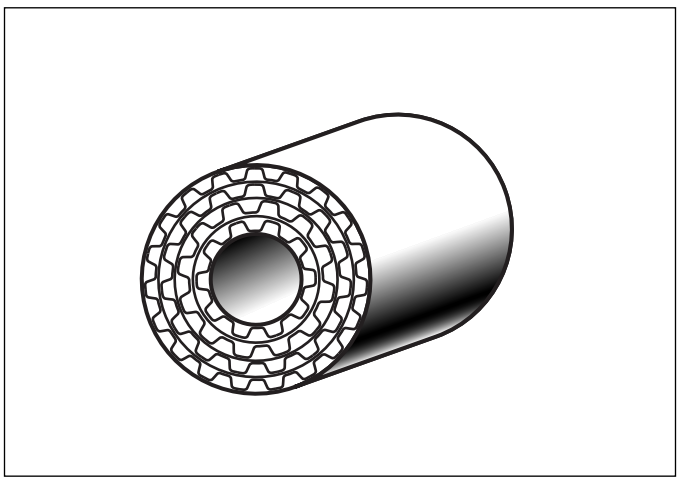
Double-Flex™

Double-Flex is a unique large cell Flex-Core for excellent formability and high specific compression properties. Double-Flex is the most formable cell configuration.



Tube-Core®

Tube-Core configuration provides a uniquely designed energy absorption system when the space envelope requires a column or small diameter cylinder. The design eliminates the loss of crush strength that occurs at the unsupported edges of conventional honeycomb. Tube-Core is constructed of alternate sheets of flat aluminum foil and corrugated aluminum foil wrapped around a mandrel and adhesively bonded. Outside diameters can range from 1/2 inch to 30 inches and lengths from 1/2 inch to 36 inches.



Other Configurations

Hexcel can design and fabricate special geometrics in response to specific needs.

Honeycomb Materials

Aluminum Honeycomb

Hexcel aluminum honeycombs are designated as follows:

Material – Cell Size – Alloy – Foil Thickness – Density

Example:

CR III – 1/4 – 5052 – .002N – 4.3

Where:

CR III® – signifies the honeycomb is treated with a corrosion-resistant coating

1/4 – is the cell size in fractions of an inch

5052 – is the aluminum alloy used

.002 – is the nominal reference foil thickness in inches

N – indicates the cell walls are nonperforated (P indicates perforated)

4.3 – is the density in pounds per cubic foot

Corrosion-Resistant Coatings

Corrosion-resistant coatings consist of a base layer underlying a primer layer. Aluminum honeycomb is available with two different corrosion-resistant coating options. These are CR III chromate-based and CR-PAA™ phosphoric acid anodized. The corrosion resistant coating is applied to the foil before the node adhesive is placed on the foil, thereby ensuring corrosion protection over the full foil surface.

CR III

CR III corrosion-resistant coating consists of a chromate-based protective layer and an organo-metallic polymer. CR III corrosion-resistant coating has been specified by the U.S. military for almost 30 years.

CR-PAA™

CR-PAA phosphoric acid anodized coating provides superior performance in certain instances. CR-PAA is superior with regards to:

- bond strength to aluminum facings in sandwich panel applications
- salt spray environments
- resistance to crack propagation
- hot/wet environments

Aluminum honeycomb is available in four different alloys, aerospace grades 5052 and 5056, and commercial grades 3104 and 3003.

5052 Alloy

Specification grade honeycomb in the 5052 H39 aluminum alloy is available for general purpose applications, in a very wide range of cell size/density combinations in the hexagonal and Flex-Core configurations. OX-Core and underexpanded cell configuration can also be provided.

5056 Alloy

Specification grade honeycomb in the 5056 H39 aluminum alloy offers superior strength over 5052 alloy honeycomb. It is also available in a broad range of cell size/density combinations in the hexagonal and Flex-Core configurations. The strength properties of 5056 alloy honeycomb are approximately 20% greater that the comparable properties of 5052 alloy honeycomb of similar cell size, foil gauge, and density.

ACG®

Aluminum Commercial Grade (ACG) honeycomb provides a low-cost aluminum honeycomb product for industrial applications. All ACG materials are provided with CR III coating. Hexcel produces ACG from 3000 series aluminum alloys. 3003 aluminum alloy is used for energy absorption applications where previous qualification studies specified this particular alloy. Hexcel also uses 3104 alloy for the manufacture of honeycomb with the flexibility to provide either 3104 or 3003 ACG, whichever is more appropriate for the application.

* Perforated honeycomb is used when the curing of the core-to-skin adhesive results in volatiles that must be vented, and in space applications where the atmosphere must be evacuated. The honeycomb may be slotted, if necessary.

Fiberglass Reinforced Honeycomb

Hexcel fiberglass reinforced honeycombs are designated as follows:

Material – Cell Size – Density

Example:

HRP – 3/16 – 4.0

Where:

HRP® – refers to the type of material

3/16 – is the cell size in fractions of an inch

4.0 – is the nominal density in pounds per cubic foot

HRP

HRP is a fiberglass fabric reinforced honeycomb dipped in a heat-resistant phenolic resin to achieve the final density. This product was developed for use at service temperatures up to 350°F. However, it is also well suited for short exposures at higher temperatures. The HRP-series honeycomb is available in the standard hexagonal configuration, as well as in the two formable configurations—OX-Core and Flex-Core.

HFT®

HFT is a fiberglass fabric reinforced honeycomb that incorporates a ±45° Fibertruss® bias weave dipped in a heat-resistant phenolic resin to achieve the final density. This material is recommended for use at service temperatures up to 350°F but is well suited for short exposures at higher temperatures. The Fibertruss configuration greatly enhances the shear properties. HFT has a much higher shear modulus than HRP or HRH®-10.

HRH®-327

HRH-327 is a fiberglass fabric, polyimide node adhesive, bias weave reinforced honeycomb dipped in a polyimide resin to achieve the final density. This material has been developed for extended service temperatures up to 500°F with short range capabilities up to 700°F.

HDC-F

HDC-F is a heavy density core fiberglass honeycomb that offers enhanced compressive properties.

Aramid Fiber Reinforced Honeycomb

Hexcel aramid-fiber reinforced honeycomb is designated as follows:

Material – Cell Size – Density

Example:

HRH-10 – 3/16 – 3.0

Where:

HRH-10 – refers to the type of material

3/16 – is the cell size in fractions of an inch

3.0 – is the nominal density in pounds per cubic foot

Hexcel manufactures aramid-fiber reinforced honeycomb from three types of para-aramid substrates. These para-aramid substrates are Nomex® (HRH-10, HRH-78, HRH-310), Kevlar® (HRH-49), and KOREX®.

HRH®-10

This product consists of Dupont's Nomex aramid-fiber paper dipped in a heat-resistant phenolic resin to achieve the final density. It features high strength and toughness in a small cell size, low density nonmetallic core. It is available in hexagonal, OX-Core, and Flex-Core configurations. It is fire-resistant and recommended for service up to 350°F.

HRH®-310

HRH-310 is made from the same aramid-fiber paper described above, except dipped in a polyimide resin to achieve the final density. It is produced in both hexagonal and overexpanded cell configurations. Outstanding features are its relatively low dielectric and loss tangent properties.

HRH®-78

HRH-78 is DuPont's non-aerospace specification grade Nomex aramid-fiber paper dipped in a heat-resistant phenolic resin to achieve the final density. HRH-78 is used in marine, rail, and other non-aerospace applications.

HRH®-49

HRH-49 is made from Kevlar 49 fabric impregnated with an epoxy resin. Significant advantages of HRH-49 honeycomb are its excellent thermal stability and relatively low coefficient of thermal expansion.

KOREX®

KOREX honeycomb is made from KOREX aramid paper dipped in a heat-resistant phenolic resin to achieve the final density. KOREX honeycomb offers improved strength-to-weight ratios and/or lower moisture absorption than Nomex honeycomb of a similar configuration.

Special Honeycomb

HFT®-G

HFT-G is a bias weave carbon fabric reinforced honeycomb dipped in either a heat-resistant phenolic resin or a polyimide resin to achieve the final density. This product was developed for use at service temperatures up to 500°F. However, it is well suited for short exposures at higher temperatures. HFT-G has a very low coefficient of thermal expansion and a high shear modulus value.

TPU®

TPU is thermoplastic polyurethane honeycomb. TPU honeycomb has unique properties of energy redirection, fatigue resistance, and flexibility.

Micro-Cell™

Micro-Cell is 1/16 inch cell size. Micro-Cell is available in 5052 and 5056 aluminum alloys and HRH-10 Nomex aramid honeycomb. Micro-Cell was developed for air directionalizing systems and for use in structural panels where minimized dimpling and distortion of the facings are required.

Acousti-Core®

Acousti-Core consists of honeycomb filled with sound absorbing fiberglass batting. Any honeycomb material may be used, with HRH-10 and aluminum the most common. The cell size must be 3/16 inch or greater. See page 29 for the noise reduction coefficient of honeycomb filled with fiberglass batting. In addition to Acousti-Core's sound absorption characteristics, two side benefits also result from the addition of the batting to the honeycomb core. The smoke generated in the N.B.S. smoke chamber is greatly reduced with the aramid Acousti-Core materials, and the thermal conductivity is reduced due to the batting.

Specifying Honeycomb

When honeycomb is specified, the following information needs to be provided:

- Material
- Cell configuration (hexagonal, OX-Core, Flex-Core, etc.)
- Cell size
- Alloy and foil gauge (aluminum honeycomb only)
- Density

Cell sizes range from 1/16" to 1", with 1/8", 3/16", 1/4", and 3/8" being the most common. Honeycomb densities range from 1.0 lb/ft^3 to 55 lb/ft^3.

Guide to Determining Which Type of Honeycomb to Specify

Determining which type of honeycomb to specify requires that the relevant possible attributes be defined for the application. The attributes that help determine the most appropriate honeycomb type can include the following:

- Cost vs. value/performance
- Piece size
- Density
- Strength
  - Compressive
  - Impact
  - Shear
  - Fatigue
  - Flatwise tensile
- Cell wall thickness
- Moisture
- Color
- Ultraviolet light exposure
- Environmental chemicals
- Processing and operating temperature range
- Flammability/fire retardance
- Thermal conductivity/insulation/heat transfer
- Electrical conductivity
- Wall surface smoothness
- Abrasion resistance
- Cushioning
- Machinability/Formability
- Facings
  - Material
  - Bonding process, adhesive, conditions
  - Thickness

Most Important Attributes of Each Honeycomb Material

Each of the honeycomb materials profiled above has specific benefits that are key to its specification. In general terms, some of the most beneficial properties of each honeycomb material are as follows:

Aluminum Honeycomb

- relatively low cost
- best for energy absorption
- greatest strength/weight
- thinnest cell walls
- smooth cell walls
- conductive heat transfer
- electrical shielding
- machinability

Aramid Fiber Honeycomb

- flammability/fire retardance
- large selection of cell sizes, densities, and strengths
- formability and parts-making experience
- insulative
- low dielectric properties

Fiberglass

- multidimensional strength of a woven structure
- heat formability
- insulative
- low dielectric properties

Carbon

- dimensional stability and retention
- strength retention and performance at high temperatures
- very low coefficient of thermal expansion
- tailorable thermal conductivity
- relatively high shear modulus

Polyurethane

- cushioning
- unaffected by moisture
- energy redirection
- fatigue-resistant
- color choices

Mechanical Properties and Test Methods

The test methods used for the honeycomb properties listed in this brochure are based on MIL-STD-401 and the applicable ASTM Standards. The properties and the test methods employed are outlined below. Unless specifically stated, the test properties listed have been performed at room temperature.

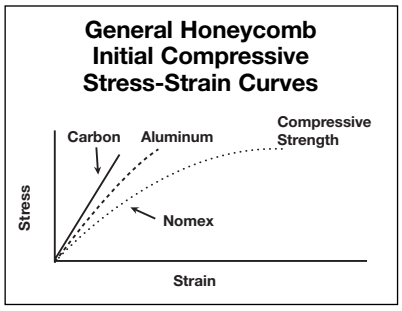
Density and Thickness Measurements

The density of honeycomb is expressed in pounds per cubic foot. Hexcel certifies that aerospace grade core will not vary in density by more than ±10% from list nominal values. The density tolerance for commercial grade aluminum core is ±17%. The density of production honeycomb is normally measured on full-size expanded sheets.

Physical dimensions and weight measurements are taken to within 0.5%. The thickness is measured to the nearest 0.001 inch in accordance with ASTM C366, Method B.

Compressive Properties

The stabilized compressive strength (also called flatwise compressive strength) represents the ultimate compressive strength of the honeycomb in pounds per square inch when loaded in the T direction. Normally for this test, facings are adhesively bonded to the honeycomb material (stabilized compressive).

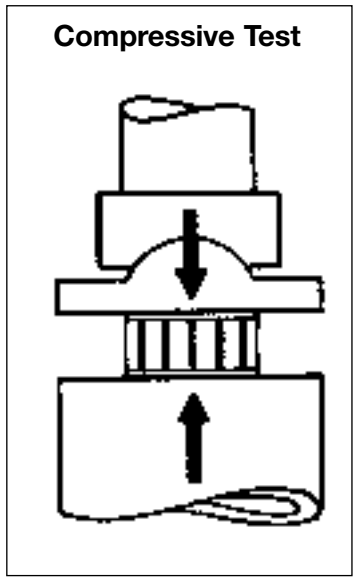


The stabilized compressive modulus, also expressed in pounds per square inch, is determined from the slope of the initial straight-line portion of the stress-strain curve. Some honeycomb materials exhibit a linear initial stress-strain relationship, while other honeycomb materials exhibit a nonlinear curved initial stress-strain relationship.

The bare compressive strength is the ultimate compressive strength of the core in pounds per square inch when loaded in the T direction without stabilization of the cell edges. The value is normally used for an acceptance criteria since this test is easier and faster to perform.

Test Methods

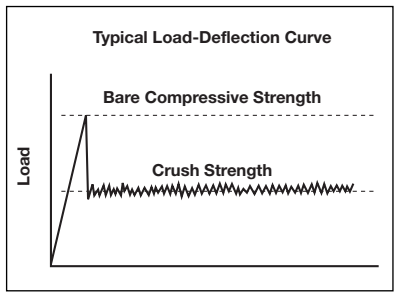
The standard specimen size for bare and stabilized compressive tests is 3" L x 3" W x 0.625" T for aluminum honeycomb and 3" L x 3" W x 0.500" T for nonmetallic cores. For cell sizes 1/2 inch or larger, a 4" x 4" or even a 6" x 6" specimen size is used to reduce the error developed by edge effect on small samples. Stabilized compressive specimens are normally prepared by bonding .032" AL 5052 thick facings to each side.



Both bare and stabilized compressive tests are conducted with self-aligning loading heads. Unless otherwise specified, the loading rate used is 0.020 inches per minute. Deflection recordings are made with a displacement transducer that measures the relative movement of the loading and bearing surfaces through the center of the specimen.

Crush Strength

After honeycomb has exceeded its ultimate compressive strength, it will continue to deform plastically and crush uniformly. The load-deflection curve shows such a typical response.



The average crush load per unit cross-sectional area is defined as the crush strength, expressed in pounds per square inch. Honeycomb will crush at virtually a constant stress level (dependent on the core material and density), hence its absorption capacity is predictable, making it ideal for energy absorption applications. When used in this manner, the core is often precrushed slightly to remove the compressive peak in the load-deflection curve. The crush strength of honeycomb decreases with increasing angle loading from the thickness.

Test Methods

Fixed loading and bearing plates are used for crush strength tests and a deflectometer is employed to measure the travel of the crosshead of the test machine. In order to obtain a meaningful crush load-deflection curve, a minimum core thickness of 0.625 inches should be used.

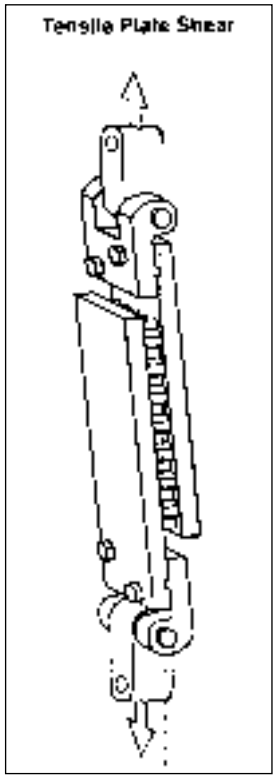
It should be noted that the crush strength values presented in this brochure are typical static test results. It has been found that under dynamic loading, these values increase nonlinearly with impact velocity, and numbers as much as 30% higher have been reported.

L and W Shear Properties

The shear strength of honeycomb as presented in this brochure refers to the ultimate stress in pounds per square inch when a shear load is applied parallel to the L–W plane. The shear modulus is the slope of the initial straight-line portion of the stress-strain curve. The values so obtained are dependent upon the orientation of the applied loading with respect to the L and W dimensions, being highest in the L direction and lowest in the W direction for hexagonal honeycomb.

Test Methods

Plate Shear Test Method



The shear strength and modulus values presented in this brochure were obtained using the compressive and/or tensile plate shear method. The specimen size for aluminum honeycomb is normally 7.5" x 2" x 0.625" T. Nonmetallic honeycombs test sample size is 6" x 2" x 0.500" T.

Thicknesses conform to MIL-C-7438 and MIL-C-8073, respectively. The specimens are bonded to 1/2-inch thick steel loading plates and then tested as shown.

The loading rate is normally 0.020 inches per minute. Shear deflections are measured with a displacement transducer that senses the relative movement of the two plates. Since some nonmetallic materials will not always have a truly linear stress-strain curve (particularly at elevated temperatures), the shear modulus is normally calculated from the slope of the initial straight-line portion of the load-deflection curve.

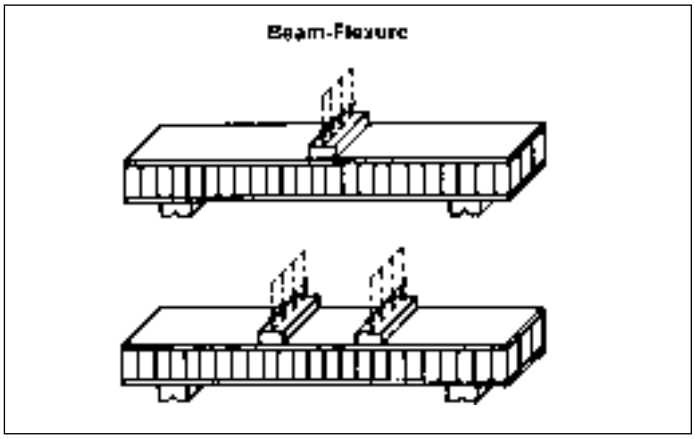
Honeycomb with densities of 8.0 pcf and higher are sometimes difficult to fail in shear by the plate shear method because of the high shear loads introduced to the adhesive bond between the core and the steel plates. In some cases, shear data from beam-flexure testing will be more applicable. This is true for thicker and also heavier density cores.

Beam-Flexure Test Method

Although the plate shear method is preferred for obtaining actual honeycomb shear strength and modulus results, the beam-flexure test is often used to evaluate overall sandwich panel performance. Experience indicates that since these values are very much dependent on the facing thickness, facing material, and loading conditions, the calculated honeycomb properties may vary considerably from one test series to the next. Many types of beam-flexure tests have been used. The two most common techniques are shown schematically below.

The specimen size is 8" x 3". The span between supports is 6" and either one or two point loading can be used. The distance between the load pads for two point loading is normally 1/3 the span. For additional details refer to MIL-C-7438 and ASTM C393.

Again, it should be stressed that the resulting beam-flexure data should only be considered a test of the facings, adhesives, and core acting as a composite sandwich structure. Core shear values obtained by flexure tests are often higher than those obtained from plate shear tests (see page 14 for correlation factors between plate shear and beam-flexure data).

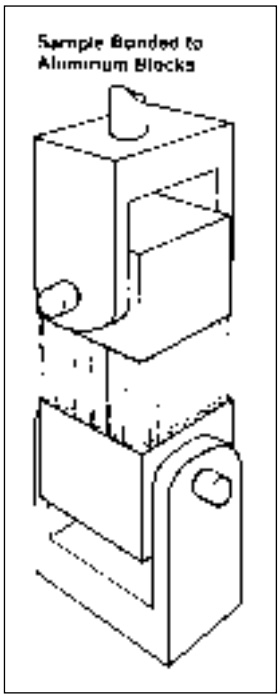


Flatwise Tensile

Flatwise tensile is used to measure bond strength of adhesives and/or the tensile strength of the honeycomb core. Most structural adhesives will be stronger than aluminum core up to about 6 pcf. This test is most useful in determining skin preparation, bonding conditions, and prepreg adhesions. See MIL-STD-401 and ASTM C297.

Additional Mechanical Properties

Numerous tests on both core materials and bonded sandwich panels have been run by Hexcel laboratory personnel for qualification to military specifications, or for internal R&D purposes.



Classification of Mechanical Properties

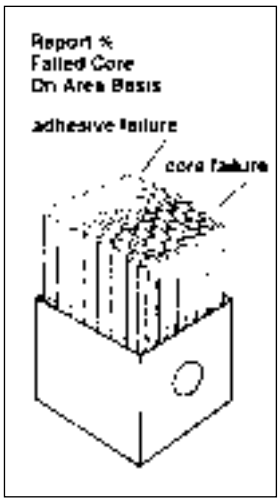
Hexcel classifies its mechanical properties data into three categories dependent upon the extent of the testing being reported. These classifications are as follows:

1. Preliminary – Data resulting from a very limited amount of testing are indicative of the properties expected, but do not necessarily represent the mean values of a normal scatter of test data. Generally, preliminary values are obtained from testing one or two blocks of a honeycomb type. Numbers followed by the letter P indicate preliminary data.

2. Typical – Data representing extensive testing of many blocks of a particular honeycomb material. A typical value is the mean average of a relatively large number of test values.

3. Minimum – Hexcel guarantees the minimum individual properties listed on standard honeycomb types.

Predicted values based upon Hexcel's educated best guess are provided in the mechanical property tables for core types when data do not exist.



Correlation of Shear Strength Data

Effect of Core Thickness on Plate Shear Strength

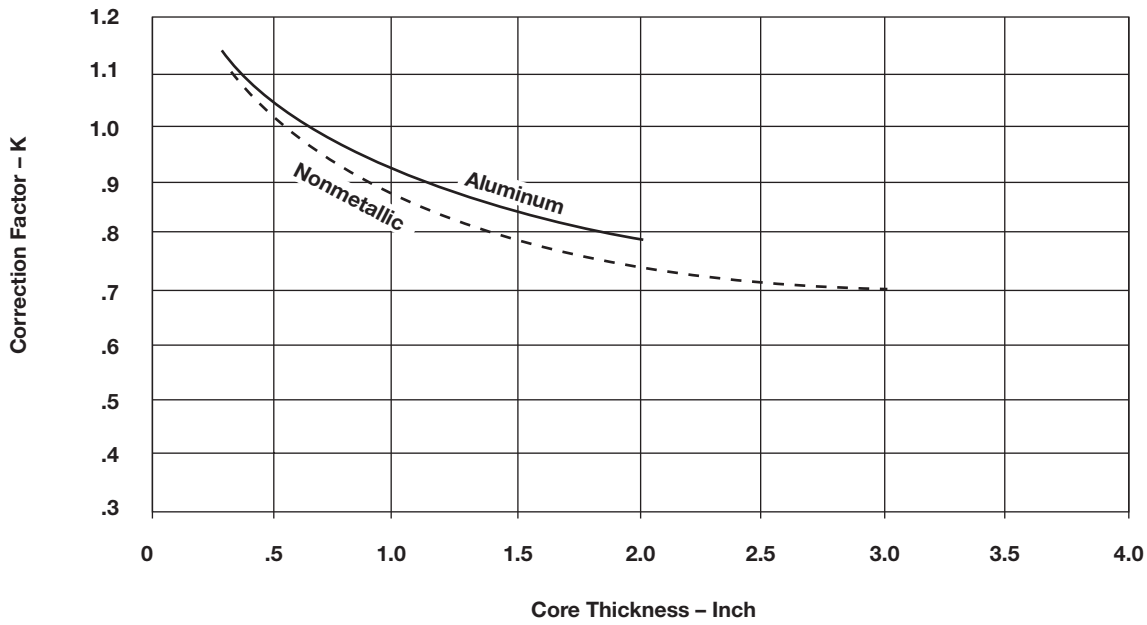
Honeycomb shear strength will vary with core thickness.

Referring to the tensile plate shear shown on page 11, it can be shown that the shear load induces a minor component parallel to the cell axis that stretches the honeycomb. The honeycomb, therefore, is not being subjected to pure shear but to a combination of shear and tension. Thicker cores will have a lower usable shear strength than thinner ones.

In view of the above, one might conclude that a plot of usable shear strength vs. core thickness would show the "true" core shear strength approached asymptotically with vanishing core thickness. However, for very thin cores the filleting of the core-to-skin adhesives has a strengthening effect on the shear data. Normally, the filleting depth is but a fraction of the core thickness, but for very thin cores this depth is a substantial fraction of the thickness and possibly the entire cell wall may be filleted. Such a phenomenon would affect the "apparent" core shear strength considerably. Also, since the filleting depth depends on the adhesive used, test results on thin cores vary from one adhesive to another.

For the above reasons and in view of typical core thickness values in actual usage, as well as several aircraft company and military specifications, aluminum honeycomb is generally tested at 0.625" T while nonmetallic honeycomb is tested at 0.500" T. However, Hexcel is often asked to qualify core materials to other thickness values. The graph below, generated from actual Hexcel data, gives correction factors for both aluminum and nonmetallic honeycomb for values other than 0.625" T and 0.500" T, respectively. The graph shows average correction factors.

Correction Factors



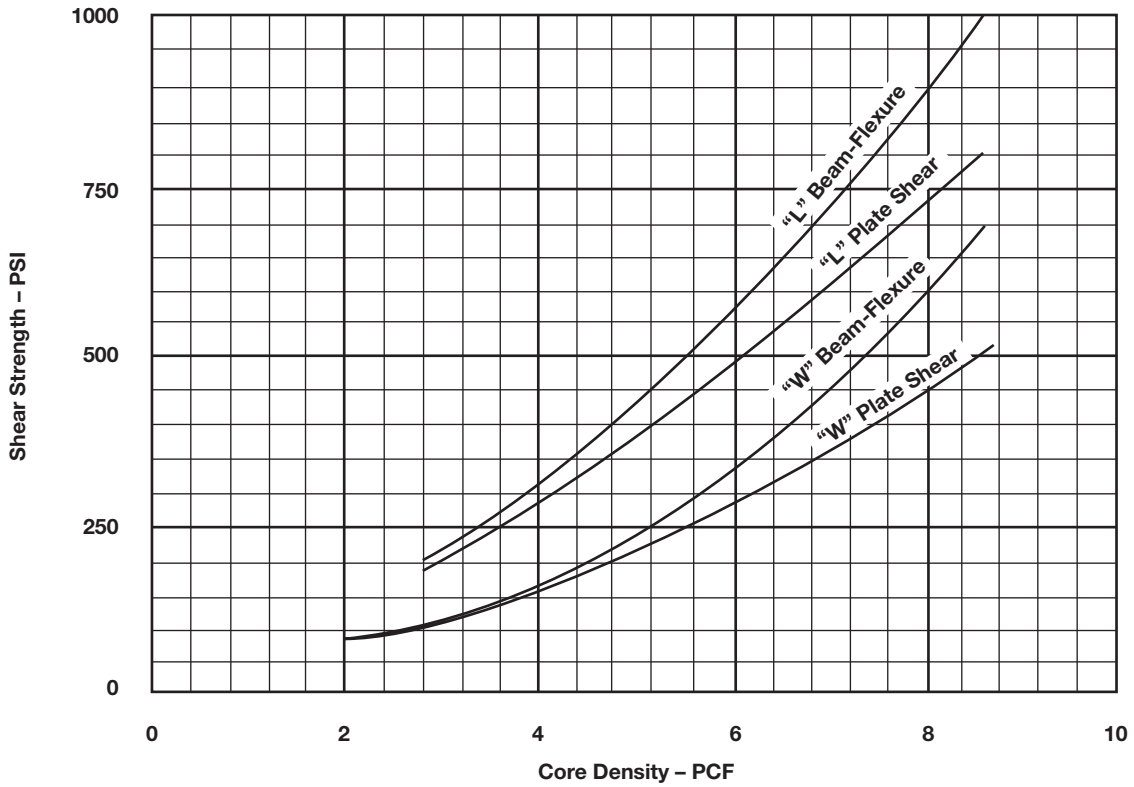
Correlation of Flexural Shear Strength Data

As previously indicated, the plate shear test method is regarded as the most desirable way of obtaining actual honeycomb shear properties. The results from the beam-flexure method have been found to be influenced by several parameters, such as facing thickness, facing material, core thickness, and loading conditions. The facing thickness alone will cause large variations because the skins are able to carry shear loads in addition to what the core carries and, furthermore, are able to take on additional shear loads after the core has yielded. Several specifications, such as MIL-C-7438, still call for beam-flexure tests for heavy density cores. We have therefore provided the graph below, which shows the results of beam-flexures on 5052 aluminum honeycomb when tested per the military specifications, and compares the L and W curves to the plate shear data for the same core type. It should be noted that the military specification calls for facing thicknesses that are different for L and W tests at a given density.

5052 Shear Strength Comparison

Plate Shear vs. Beam-Flexures
Typical Values

Beam-Flexures per MIL-C-7438E with facing thickness as specified



Mechanical Property Tables

The most commonly measured honeycomb properties are bare compressive strength, stabilized compressive strength and modulus, crush strength, and L direction and W direction plate shear strength and moduli.

The following tables contain the mechanical properties of the various honeycomb core types for which Hexcel has data. It should be noted that some of the core types listed are not always readily available.

Hexcel has produced additional core types not listed, and in some cases larger or smaller cell sizes, intermediate or higher densities, and special materials can be provided.

For detailed information on standard or special sheet sizes, refer to the appropriate data sheets.

Crush strength values presented in this brochure are to be used for preliminary designs. For core densities below 3 pcf, these values vary as much as ±20%. For all other densities, crush strength values vary by ±15%.

The honeycomb properties that follow are for the compressive strength and modulus in the T direction, and the shear strength and moduli in the LT and WT directions. The honeycomb properties in other secondary directions are extremely low compared to the properties provided for the primary designed orientation of honeycomb. The L and W direction compressive properties are typically less than 5% of the compressive properties in the T direction. The plate shear strength is substantially less in the LW plane than in either the LT or WT plane, while the plate shear modulus in the LW plane is typically less than 5% of the plate shear modulus in either the LT plane or WT plane.

In addition to compressive strength and plate shear properties, sometimes other honeycomb properties are important for particular applications. These include fatigue for repeated loads, creep from constant stress over a long period of time (especially at elevated temperatures or when combined with other materials), and flatwise tensile strength.

Note: See page 12 for definitions of "preliminary," "typical," and "minimum."

5052 Alloy Hexagonal Aluminum Honeycomb – Specification Grade

Both CR-PAA and CR III corrosion-resistant coating

Hexcel Honeycomb Designation Cell Size – Alloy – Foil Gauge	Nominal Density pcf	Compressive					Crush Strength psi	Plate Shear					
		Bare		Stabilized				L Direction			W Direction		
		Strength psi		Strength psi		Modulus ksi		Strength psi		Modulus ksi	Strength psi		Modulus ksi
		typ	min	typ	min	typ	typ	typ	min	typ	typ	min	typ
1/16 – 5052 – .0007	6.5	950	740	1000	780	275	505x	560	440	90.0	350	270	40.0
1/16 – 5052 – .001	9.2	1500	1170	1550	1200	420	750x	850	660	150.0	520	400	53.0
1/16 – 5052 – .0015	12.4	2430	1900	2650	2000	650	1200x	1150	900	210.0	715	560	65.0
1/8 – 5052 – .0007	3.1	285	200	300	215	75	130	210	155	45.0	130	90	22.0
1/8 – 5052 – .001	4.5	550	375	570	405	150	260	340	285	70.0	220	168	31.0
1/8 – 5052 – .0015	6.1	980	650	1020	680	240	450	560	455	98.0	340	272	41.0
1/8 – 5052 – .002	8.1	1500	1000	1560	1100	350	750	800	670	135.0	470	400	54.0
1/8 – 5052 – .0025	10.0	2100p	1575p	2250p	1685p	500x	1050x	980p	735p	175.0p	550p	415p	65.0p
1/8 – 5052 – .003	12.0	2700	2100	2900	2200	900	1350x	1940I	1250I	210.0x	1430I	1000I	78.0x
5/32 – 5052 – .0007	2.6	220	150	240	160	55	90	165	120	37.0	100	70	19.0
5/32 – 5052 – .001	3.8	395	285	410	300	110	185	270	215	56.0	165	125	26.4
5/32 – 5052 – .0015	5.3	690	490	720	535	195	340	420	370	84.0	270	215	36.0
5/32 – 5052 – .002	6.9	1080	770	1130	800	285	575	590	540	114.0	375	328	46.4
5/32 – 5052 – .0025	8.4	1530	1070	1600	1180	370	800	760	690	140.0	475	420	56.0
3/16 – 5052 – .0007	2.0	160	90	175	100	34	60	120	80	27.0	70	46	14.3
3/16 – 5052 – .001	3.1	290	200	335	215	75	130	210	155	45.0	125	90	22.0
3/16 – 5052 – .0015	4.4	520	360	550	385	145	250	330	280	68.0	215	160	30.0
3/16 – 5052 – .002	5.7	820	560	860	600	220	390	460	410	90.0	300	244	38.5
3/16 – 5052 – .0025	6.9	1120	770	1175	800	285	575	590	540	114.0	375	328	46.4
3/16 – 5052 – .003	8.1	1600	1000	1720	1100	350	750	725	670	135.0	480	400	54.0
1/4 – 5052 – .0007	1.6	90	60	100	70	20	40	85	60	21.0	50	32	11.0
1/4 – 5052 – .001	2.3	190	120	210	130	45	75	140	100	32.0	85	57	16.2
1/4 – 5052 – .0015	3.4	340	240	370	250	90	150	230	180	50.0	140	105	24.0
1/4 – 5052 – .002	4.3	500	350	540	370	140	230	320	265	66.0	200	155	29.8
1/4 – 5052 – .0025	5.2	690	500	760	510	190	335	410	360	82.0	265	200	35.4
1/4 – 5052 – .003	6.0	990	630	1100	660	235	430	530	445	96.0	340	265	40.5
1/4 – 5052 – .004	7.9	1420	970	1490	1050	340	725	700	650	130.0	440	390	52.8
3/8 – 5052 – .0007	1.0	50	20	55	20	10	25	45	32	12.0	30	20	7.0
3/8 – 5052 – .001	1.6	90	60	95	70	20	40	85	60	21.0	50	32	11.0
3/8 – 5052 – .0015	2.3	190	120	200	130	45	75	135	100	32.0	80	57	16.2
3/8 – 5052 – .002	3.0	285	190	310	200	70	120	200	145	43.0	125	85	21.2
3/8 – 5052 – .0025	3.7	370	270	410	285	105	180	250	200	55.0	160	115	26.0
3/8 – 5052 – .003	4.2	520	335	560	355	135	220	310	255	65.0	200	150	29.0
3/8 – 5052 – .004	5.4	740	500	800	535	200	360	430	380	86.0	280	228	36.8
3/8 – 5052 – .005	6.5	950	700	1000	750	265	505	545	500	105.0	350	300	43.5

Notes:
Test data obtained at 0.625" thickness.
I = Beam shear for 1/8 12.0 pcf product.
p = Preliminary (see page 12).
x = Predicted value.

5056 Alloy Hexagonal Aluminum Honeycomb – Specification Grade

Both CR-PAA and CR III corrosion-resistant coating

Hexcel Honeycomb Designation Cell Size – Alloy – Foil Gauge	Nominal Density pcf	Compressive					Crush Strength psi	Plate Shear					
		Bare		Stabilized				L Direction			W Direction		
		Strength psi		Strength psi		Modulus ksi		Strength psi		Modulus ksi	Strength psi		Modulus ksi
		typ	min	typ	min	typ	typ	typ	min	typ	typ	min	typ
1/16 – 5056 – .001	9.2	1700p	1300p	1800p	1400p	500p	850x	980p	760p	155.0p	600p	460p	50.0p
1/8 – 5056 – .0007	3.1	320	250	350	260	97	170	250	200	45.0	155	110	20.0
1/8 – 5056 – .001	4.5	630	475	690	500	185	320	440	350	70.0	255	205	28.0
1/8 – 5056 – .0015	6.1	1120	760	1200	825	295	535	690	525	102.0	400	305	38.0
1/8 – 5056 – .002	8.1	1750	1200	1900	1300	435	810	945	740	143.0	560	440	51.0
5/32 – 5056 – .0007	2.6	250	180	265	185	70	120	200	152	37.0	115	80	17.0
5/32 – 5056 – .001	3.8	450	360	500	375	140	235	335	272	57.0	195	155	24.0
5/32 – 5056 – .0015	5.3	820	615	865	650	240	420	550	435	85.0	325	250	33.0
5/32 – 5056 – .002	6.9	1220	920	1340	1000	350	650	760	610	118.0	430	360	43.0
3/16 – 5056 – .0007	2.0	190	110	200	120	45	75	140	105	27.0	85	50	13.0
3/16 – 5056 – .001	3.1	380	250	410	260	97	170	265	200	45.0	150	110	20.0
3/16 – 5056 – .0015	4.4	620	460	670	490	180	310	425	340	68.0	245	198	27.0
3/16 – 5056 – .002	5.7	920	685	1000	735	270	480	565	480	94.0	330	280	36.0
1/4 – 5056 – .0007	1.6	100	75	110	80	30	50	90	78	20.0	60	38	10.5
1/4 – 5056 – .001	2.3	240	145	265	155	58	100	180	130	32.0	100	62	15.0
1/4 – 5056 – .0015	3.4	400	300	480	315	115	200	290	230	50.0	175	130	22.0
1/4 – 5056 – .002	4.3	580	440	620	465	172	300	400	325	67.0	230	190	27.0
1/4 – 5056 – .0025	5.2	790	600	820	645	230	410	490	425	84.0	300	245	32.0
3/8 – 5056 – .0007	1.0	55	25	60	35	15	35	55	45	15.0	35	25	6.8
3/8 – 5056 – .001	1.6	100	75	110	80	30	50	90	78	20.0	60	38	10.5
3/8 – 5056 – .0015	2.3	215	155	225	155	58	100	170	130	32.0	95	62	15.0
3/8 – 5056 – .002	3.0	320	240	340	260	92	160	245	190	43.0	145	100	19.0

Notes:
p = Preliminary (see page 12). x = Predicted value.

Aluminum Commercial Grade (ACG) for 3000 Series Alloy

Hexcel Honeycomb Designation Material – Cell Size	Nominal Density pcf	Compressive			Crush Strength psi	Plate Shear			
		Bare	Stabilized			L Direction		W Direction	
		Strength psi	Strength psi	Modulus ksi		Strength psi	Modulus ksi	Strength psi	Modulus ksi
		typ	typ	typ	typ	typ	typ	typ	typ
ACG – 1/4	4.8	630	660	148	245	365	70	215	38
ACG – 3/8	3.3	340	370	92	120	230	45	130	22
ACG – 1/2	2.3	190	205	40	60	140	28	80	14
ACG – 3/4	1.8	120	130	24	45	100	20	65	11
ACG – 1	1.3	80	85	16p	25	65	14	45	7

Notes:
Test data obtained at 0.625" thickness.
p = Preliminary (see page 12).

5052 Alloy Rigicell™ Aluminum Corrugated Honeycomb

Both CR-PAA and CR III corrosion-resistant coating

Hexcel Honeycomb Designation Cell Size – Alloy Foil Gauge – Configuration	Nominal Density pcf	Crush Strength psi	Compressive Strength			Beam Shear Strength			
			Bare psi	Stabilized psi	Modulus ksi	L Direction psi	Modulus ksi	W Direction psi	Modulus ksi
		typ	typ	typ		typ		typ	
1/8 – 2 – .003-STD	12.0	1600	2300	2400	560x	1950	210x	1500	75x
1/8 – 2 – .0038-STD	14.5	2150	2900	3050	650x	2200	260x	1600	80x
1/8 – 2 – .006-STD	22.1	4000	5100	5200	970x	3000	440x	2050	100x
1/8 – 2 – .006-R2	38.0	6500	8500	8700	1650x	4300p	950x	2200p	140x
1/8 – 2 – .006-2R2	55.0	–	12500x	13000p	2400x	4900p	1370x	2610p	180x
3/16 – 2 – .006-STD	15.7	2400	3200	3300	700x	2400x	280x	1500x	85x
3/16 – 2 – .006-R2S	25.0	4400p	5700	5800p	1100x	3350p	670x	1700p	105x
1/4 – 2 – .006-STD	10.5	1350	2100	2200	980x	1300x	180x	800x	70x

Notes:
Test data obtained at 0.625" thickness.
p = Preliminary (see page 12).
x = Predicted value.
R2 = Reinforced (inter leaf) every ribbon, non-staggered.
R2S = Reinforced (inter leaf) every ribbon, staggered.
2R2 = Corrugation double lap, reinforced (inter leaf) every ribbon, non-staggered

Aluminum Flex-Core

Both CR-PAA and CR III corrosion-resistant coating

5052 Alloy Aluminum Flex-Core – Specification Grade

Hexcel Honeycomb Designation Alloy/Cell Count – Foil Gauge	Nominal Density pcf	Compressive					Crush Strength psi	Plate Shear					
		Bare		Stabilized				L Direction			W Direction		
		Strength psi		Strength psi		Modulus ksi		Strength psi		Modulus ksi	Strength psi		Modulus ksi
		typ	min	typ	min	typ	typ	min	typ	min	typ	min	typ
5052/F40 – .0013	2.1	200	126	225	157	65	80	90	63	18.0	50	37	10.0
5052/F40 – .0016	2.5	260	200	285	215	90x	120x	120x	95x	24.0x	70x	55x	11.0x
5052/F40 – .0019	3.1	350	238	380	280	125	165	165	126	32.0	95	75	13.0
5052/F40 – .0025	4.1	525	378	560	420	185	250	260	182	45.0	165	115	17.0
5052/F40 – .0037	5.7	935	630	1050	700	290	380	430	280	68.0	260	170	23.0
5052/F80 – .0013	4.3	615	402	650	455	195	275x	300	196	45.0	190	120	20.0
5052/F80 – .0019	6.5	1140	700	1250	735	310	510x	500	308	72.0	310	180	24.0
5052/F80 – .0025	8.0	1600	1100	1750	1120	400	720x	645	434	98.0	440	260	31.0
5052 Alloy Aluminum Double-Flex – Specification Grade													
5052/DF25 – .0025	2.7	360	270	390	290	120p	145p	185	140	29.0p	100	80	13.0p
5052/DF25 – .0047	4.8	850	680	960	720	220x	430p	370	290	50.0p	240	180	22.0p
5052/DF40 – .0025	4.2	760p	600p	850p	680p	190x	350p	280p	220p	30.0p	190p	150p	17.0p
5056 Alloy Aluminum Flex-Core – Specification Grade													
5056/F40 – .0014	2.1	240	150	260	182	65	105x	105	74	18.0	55	42	10.0
5056/F40 – .0020	3.1	460	284	510	329	125	205x	200	150	32.0	120	90	13.0
5056/F40 – .0026	4.1	680	440	740	483	185	305x	310	217	45.0	200	132	17.0
5056/F80 – .0014	4.3	780	475	860	518	195	350x	375	235	47.0	240	138	20.0
5056/F80 – .0020	6.5	1400	805	1500	910	310	630x	650	364	73.0	420	213	24.0
5056/F80 – .0026	8.0	1800	1210	1950	1260	410	810x	770	518	100.0	475	307	32.0

Notes: Test data obtained at 0.625" thickness. p = Preliminary (see page 12). x = Predicted values.

HRP Fiberglass Reinforced Phenolic Honeycomb

Hexcel Honeycomb Designation / Material – Cell Size – Density	Compressive					Plate Shear					
	Bare		Stabilized			L Direction			W Direction		
	Strength psi		Strength psi		Modulus ksi	Strength psi		Modulus ksi	Strength psi		Modulus ksi
Hexagonal	typ	min	typ	min	typ	typ	min	typ	typ	min	typ
HRP – 3/16 – 4.0	480	400	590	480	57	310	210	13.0	160	130	6.5
HRP – 3/16 – 5.5	800	620	900	750	95	490	390	19.0	265	200	11.0
HRP – 3/16 – 7.0	1150	900	1300	1040	136	650	510	30.0	370	290	14.0
HRP – 3/16 – 8.0	1350	1100	1530	1280	164	750	TBD	TBD	460	370	19.0
HRP – 3/16 – 12.0	2300	1800	2520	1960	260	985	815	48.0	675	525	28.0
HRP – 1/4 – 3.5	390	280	455	400	46	250	180	10.0	125	100	5.0
HRP – 1/4 – 4.5	585	480	640	560	70	355	280	15.0	200	155	8.0
HRP – 1/4 – 5.0	680	530	820	660	84	400	305	20.0	230	180	10.0
HRP – 1/4 – 6.5	1025	850	1180	920	120	580	450	25.0	330	260	13.0
HRP – 3/8 – 2.2	165	125	180	145	13	120	90	6.0	60	45	3.0
HRP – 3/8 – 3.2	315	260	390	350	38	205	160	12.0	110	85	5.0
HRP – 3/8 – 4.5	610	450	690	550	65	325	260	14.0	190	150	8.0
HRP – 3/8 – 6.0	900	750	1000	800	100	520	400	25.0	300	210	12.0
HRP – 3/8 – 8.0	1400	1000	1540	1180	150	700	540	27.0	450	350	18.0
OX-Core											
HRP/OX – 1/4 – 4.5	560	480	675	540	43	250	200	7.0	260	210	15.0
HRP/OX – 1/4 – 5.5	775	580	890	670	65	300	230	10.0	330	255	18.0
HRP/OX – 1/4 – 7.0	1150	850	1230	990	84	395	310	14.0	450	350	20.0
HRP/OX – 3/8 – 3.2	340	260	390	300	32	140	110	4.5	150	120	9.0
HRP/OX – 3/8 – 5.5	700	580	820	615	60	270	210	10.0	355	275	17.0
Flex-Core											
HRP/F35 – 2.5	180	135	240	185	25	125	95	12.0	70	55	7.0
HRP/F35 – 3.5	320	245	400	300	37	200	140	15.0	105	75	10.0
HRP/F35 – 4.5	440	340	600	470	49	280	220	22.0	140	110	12.0
HRP/F50 – 3.5	315	225	395	255	37	170	130	16.0	90	65	8.0
HRP/F50 – 4.5	420	340	600	500	49	265	200	25.0	140	100	13.0
HRP/F50 – 5.5	700	540	800	680	61	440	330	40.0	235	180	18.0

Note: Test data obtained at 0.500" thickness.

HFT Fiberglass Reinforced Phenolic Honeycomb (Fibertruss Bias Weave)

Hexcel Honeycomb Designation / Material – Cell Size – Density	Compressive			Plate Shear					
	Stabilized			L Direction			W Direction		
	Strength psi		Modulus ksi	Strength psi		Modulus ksi	Strength psi		Modulus ksi
	typ	min	typ	typ	min	typ	typ	min	typ
HFT – 1/8 – 3.0	350	270	23.0	195	150	19.0	95	75	7.5
HFT – 1/8 – 4.0	560	420	46.0	315	240	25.0	150	120	12.0
HFT – 1/8 – 5.5	900	700	69.0	525	410	40.0	250	190	16.0
HFT – 1/8 – 8.0	1750	1500	100.0	675	525	45.0	480	400	21.5
HFT – 3/16 – 2.0	170	130	17.0	115	90	15.0	60	50	5.0
HFT – 3/16 – 3.0	365	275	34.0	200	155	19.0	100	80	9.0
HFT – 3/16 – 4.0	550	460	44.0	340	270	25.0	190	140	12.0
HFT – 3/8 – 4.0	500	400		380	290	27.0	195	140	13.0
HFT/OX – 3/16 – 6.0	1200	1020	63.0	320	240	18.0	260	190	19.0

Notes:
Test data obtained at 0.500" thickness.
HFT Fiberglass Reinforced Phenolic Honeycomb normally is not tested for bare compressive strength.

HRH-327 Fiberglass Reinforced Polyimide Honeycomb

Hexcel Honeycomb Designation Material – Cell Size – Density	Compressive			Plate Shear					
	Stabilized			L Direction			W Direction		
	Strength psi		Modulus ksi	Strength psi		Modulus ksi	Strength psi		Modulus ksi
	typ	min	typ	typ	min	typ	typ	min	typ
HRH-327 – 1/8 – 3.2	310	220	27	195	140	19	95	70	7.5
HRH-327 – 1/8 – 5.5	790p	600p	80p	465p	300p	30p	245p	175p	14.5p
HRH-327 – 3/16 – 4.0	440p	340p	40p	280p	200p	24p	130p	90p	10.0p
HRH-327 – 3/16 – 4.5	520	400	45	320	220	33	150	110	11.0
HRH-327 – 3/16 – 5.0	600p	480p	68p	370p	280p	37p	180p	135p	12.0p
HRH-327 – 3/16 – 6.0	780	625	87	460	345	45	230	170	15.0
HRH-327 – 3/16 – 8.0	1210	1000	100	700	490	55	420	300	22.0
HRH-327 – 3/8 – 4.0	440	325	50	280	195	29	150	100	12.0
HRH-327 – 3/8 – 5.5	680	540	78	420	300	41	210	160	13.0
HRH-327 – 3/8 – 7.0	1000p	875p	106p	575p	480p	53p	340p	280p	18.0p

Notes:
Test data obtained at 0.500" thickness.
p = Preliminary (see page 12).
HRH-327 Fiberglass Reinforced Polyimide Honeycomb normally is not tested for bare compressive strength.

HRH-10 Aramid Fiber/Phenolic Resin Honeycomb

Hexcel Honeycomb Designation Material – Cell Size – Density	Compressive					Plate Shear					
	Bare		Stabilized			L Direction			W Direction		
	Strength psi		Strength psi		Modulus ksi	Strength psi		Modulus ksi	Strength psi		Modulus ksi
Hexagonal	typ	min	typ	min	typ	typ	min	typ	typ	min	typ
HRH-10 – 1/16 – 3.4	195	160	205	170	20	155	125	6.0	85	65	2.9
HRH-10 – 1/8 – 1.8	105	85	115	95	8	90	75	3.8	50	40	1.5
HRH-10 – 1/8 – 3.0	290	235	325	270	20	175	155	6.5	100	85	3.5
HRH-10 – 1/8 – 4.0	520	400	575	470	28	255	225	8.6	140	115	4.7
HRH-10 – 1/8 – 5.0	700	560	770	620	37	325	275	10.2	175	150	5.4
HRH-10 – 1/8 – 6.0	1050	850	1125	925	60	385	330	13.0	200	170	6.5
HRH-10 – 1/8 – 8.0	1675	1370	1830	1450	78	480	400	16.0	260	210	9.5
HRH-10 – 1/8 – 9.0	2000	1525	2100	1600	90	515	425	17.5	300	250	11.0
HRH-10 – 3/16 – 1.5	85	70	95	80	6	65	50	3.0	35	28	1.6
HRH-10 – 3/16 – 1.8	120	95	130	105	8	90	75	3.8	50	40	1.9
HRH-10 – 3/16 – 2.0	135	110	150	130	11	95	80	4.3	55	45	2.1
HRH-10 – 3/16 – 3.0	275	235	325	270	20	175	140	6.5	100	85	3.4
HRH-10 – 3/16 – 4.0	500	430	540	470	28	245	215	7.8	140	110	4.7
HRH-10 – 3/16 – 6.0	935	780	1020	865	60	420	370	13.0	225	200	6.5
HRH-10 – 1/4 – 1.5	80	65	90	75	6	70	55	3.0	35	25	1.3
HRH-10 – 1/4 – 2.0	120	100	130	105	11	95	80	4.2	45	36	2.0
HRH-10 – 1/4 – 3.1	285	240	310	265	21	185	160	6.5	90	75	3.0
HRH-10 – 1/4 – 4.0	440	360	480	390	28	250	205	8.0	125	100	3.5
HRH-10 – 3/8 – 1.5	95	75	105	80	6	70	55	3.0	35	25	1.5
HRH-10 – 3/8 – 2.0	140	115	155	125	11	90	72	3.7	55	36	2.4
HRH-10 – 3/8 – 3.0	255	210	270	225	17	200	160	6.5	100	80	3.0
HRH-10 – 3/4 – 1.5	70p	50p	80p	55p	7p	70p	55p	3.4p	35p	25p	1.7p
OX-Core											
HRH-10/OX – 3/16 – 1.8	100	80	110	90	7	50	40	2.0	60	50	3.0
HRH-10/OX – 3/16 – 3.0	320	260	350	285	17	105	95	2.5	120	100	6.0
HRH-10/OX – 3/16 – 4.0	600	500	650	550	26	130	105	4.6	150	130	8.4
HRH-10/OX – 1/4 – 3.0	350	280	385	310	17	110	90	3.0	135	110	6.0
Flex-Core											
HRH-10/F35 – 2.5	200	150	235	175	12	110	90	4.0	65	50	2.5
HRH-10/F35 – 3.5	410	320	430	330	24	220	170	6.0	120	90	3.7
HRH-10/F35 – 4.5	580	440	620	480	33	300	230	9.0	190	150	4.3
HRH-10/F50 – 3.5	380	300	400	310	24	175	130	5.5	100	75	3.6
HRH-10/F50 – 4.5	565	450	585	470	33	330	250	9.5	175	140	4.7
HRH-10/F50 – 5.0	670	520	690	540	37	380	300	10.0	215	170	5.2
HRH-10/F50 – 5.5	800	620	850	660	42	400	320	10.5	230	180	5.7

Notes:Test data obtained at 0.500" thickness.
p = Preliminary (see page 12).

HRH-310 Aramid Fiber/Polyimide Resin Honeycomb

Hexcel Honeycomb Designation Material – Cell Size – Density	Compressive			Plate Shear			
	Bare	Stabilized		L Direction		W Direction	
	Strength psi	Strength psi	Modulus ksi	Strength psi	Modulus ksi	Strength psi	Modulus ksi
	typ	typ	typ	typ	typ	typ	typ
HRH-310 – 1/8 – 1.8	60	70	–	57	3.4	30	1.0
HRH-310 – 1/8 – 5.0	660	730	40	325	10.0	175	5.0

Notes: Test data obtained at 0.500" thickness.
Data are from a very limited amount of testing.

HRH-78 Nomex Commercial Grade Aramid Fiber/Phenolic Resin Honeycomb

Hexcel Honeycomb Designation Material – Cell Size – Density	Compressive			Plate Shear			
	Bare	Stabilized		L Direction		W Direction	
	Strength psi	Strength psi	Modulus ksi	Strength psi	Modulus ksi	Strength psi	Modulus ksi
	typ	typ	typ	typ	typ	typ	typ
HRH-78 – 1/8 – 3.0	280	315	18.5p	160	5.3p	90	3.1p
HRH-78 – 1/8 – 8.0	1600	1750	60.0p	470	15.0p	250	7.8p
HRH-78 – 3/16 – 3.0	270	330	18.2p	124	4.6p	81	3.5p
HRH-78 – 3/16 – 6.0	1125	1200	–	450	13.0p	235	5.5p
HRH-78 – 1/4 – 3.0	265	285	19.0p	120	4.6p	80	3.0p
HRH-78 – 3/8 – 1.5	85	95	6.0p	60	2.5p	33	1.5p

Notes: Test data obtained at 0.500" thickness. p = Preliminary value obtained from limited testing (see page 12).

HRH-49 Kevlar 49 Honeycomb

Hexcel Honeycomb Designation Material – Cell Size – Density	Compressive			Plate Shear					
	Stabilized			L Direction			W Direction		
	Strength psi		Modulus ksi	Strength psi		Modulus ksi	Strength psi		Modulus ksi
	typ	min	typ	typ	min	typ	typ	min	typ
HRH-49 – 1/4 – 2.1	130	100	25	85	50	2.7	40	30	1.3

Note: Test data obtained at 0.500" thickness.

KOREX Aramid Fiber/Phenolic Resin Honeycomb

Hexcel Honeycomb Designation Material – Cell Size – Density	Compressive		Plate Shear			
	Bare	Stabilized	L Direction		W Direction	
	Strength psi	Strength psi	Strength psi	Modulus ksi	Strength psi	Modulus ksi
	typ	typ	typ	typ	typ	typ
KOREX – 1/8 – 3.0	260	280	178	14.4	105	7.0
KOREX – 1/8 – 4.5	530	590	360	29.5	220	12.0
KOREX – 1/8 – 6.0	980	1000	520	34.5	310	16.0
KOREX – 5/32 – 2.4	230	260	168	11.7	101	6.6
KOREX – 3/16 – 2.0	150	160	85	12.0	70	5.0
KOREX – 3/16 – 3.0	280	280	220	20.0	115	9.0
KOREX – 3/16 – 4.5	580	660	370	31.0	220	11.4
KOREX – 1/4 – 1.5	100	110	85	7.4	47	3.1
KOREX – 3/8 – 4.5	520	560	343	22.4	189	8.3
KOREX – 3/80X – 1.5	90	100	65	4.2	49	4.2

Notes: Test data obtained at 0.500" thickness. Data are from a very limited amount of testing.

TPU Thermoplastic Polyurethane Honeycomb

Hexcel Honeycomb Designation Material – Cell Size – Film Gauge – Density
TPU – 7/32 – .008 – 7.2
TPU – 9/32 – .012 – 8.0
TPU – 7/16 – .0015 – 7.4

Comparison of Typical Mechanical Properties and Other Design Considerations

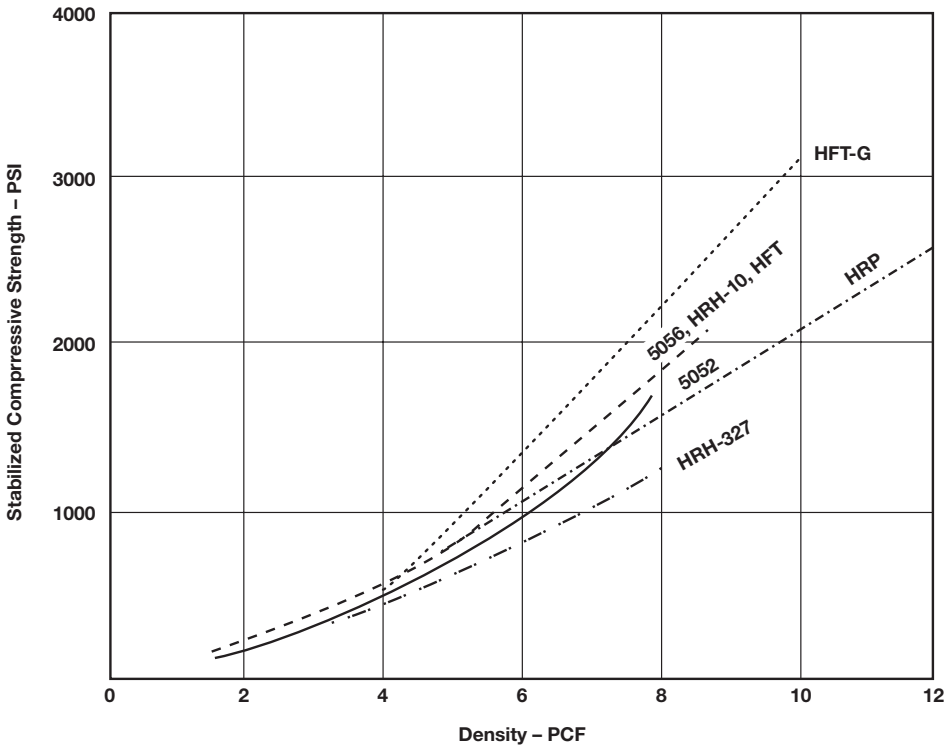
The curves on the following pages compare the typical mechanical properties of several honeycomb types. They are intended to show relative strength and shear moduli at ambient temperature. Included also are two graphs showing the effect of elevated temperatures on honeycomb strength after 30 minutes and 100 hours of exposure.

The selection of a particular honeycomb type is, of course, not only dependent on the mechanical properties. Many other factors have to be considered. A few of these considerations and the relative ratings of several honeycomb materials are presented in the table below. In overall economics or value analysis, one should also keep in mind such factors as tooling requirements, shop losses, previous experience, and, of course, the optimization of structural properties at minimum weight for the overall structure. Hexcel can assist with honeycomb material selection and trade-off analysis.

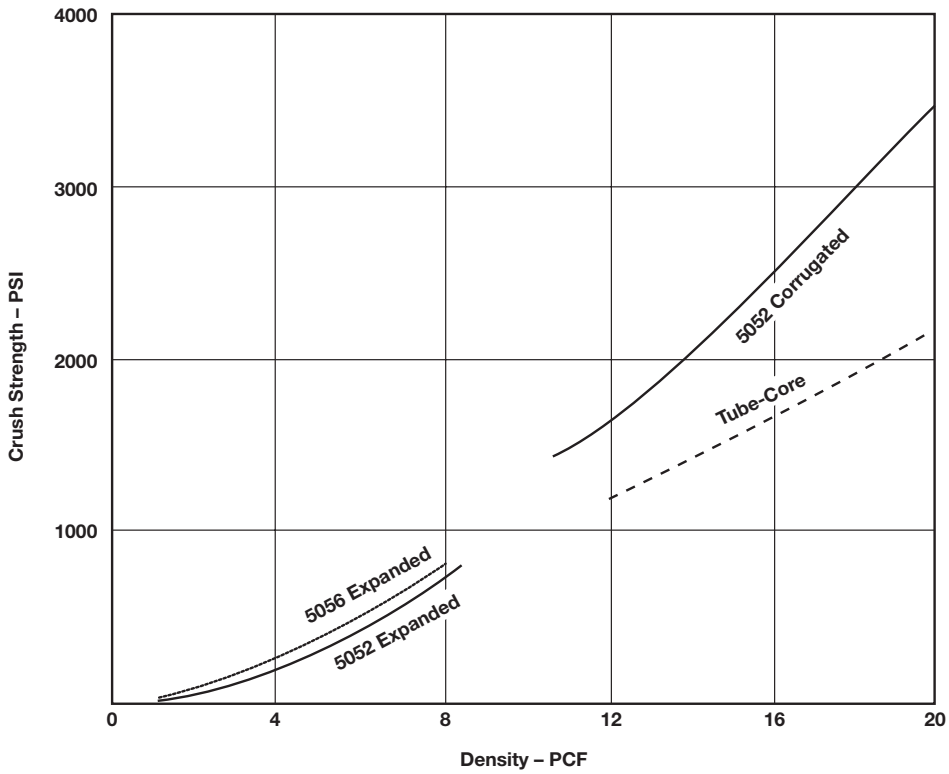
Attributes	5052 5056 CR III	5052 5056 CR-PAA	ACG CR III	HRP	HFT	HRH-327	HRH-10	KOREX	HFT-G-327
Relative Cost	Mod Low	Med	Very Low	Mod High	High	Very High	Med	High	Very High
Maximum Long-Term Temperature	350°F	350°F	350°F	350°F	350°F	500°F	350°F	350°F	500°F
Flammability Resistance	E	E	E	E	E	E	E	E	E
Impact Resistance	G	G	G	F	G	F	E	E	F
Moisture Resistance	E	E	E	E	E	E	G	E	E
Fatigue Strength	G	G	G	G	G	G	E	E	E
Heat Transfer	High	High	High	Low	Low	Low	Low	Low	Med
Corrosion Resistance	G	E	G	E	E	E	E	E	E

E = Excellent.
G = Good.
F = Fair.
P = Poor.
Mod = Moderately.
Med = Medium.

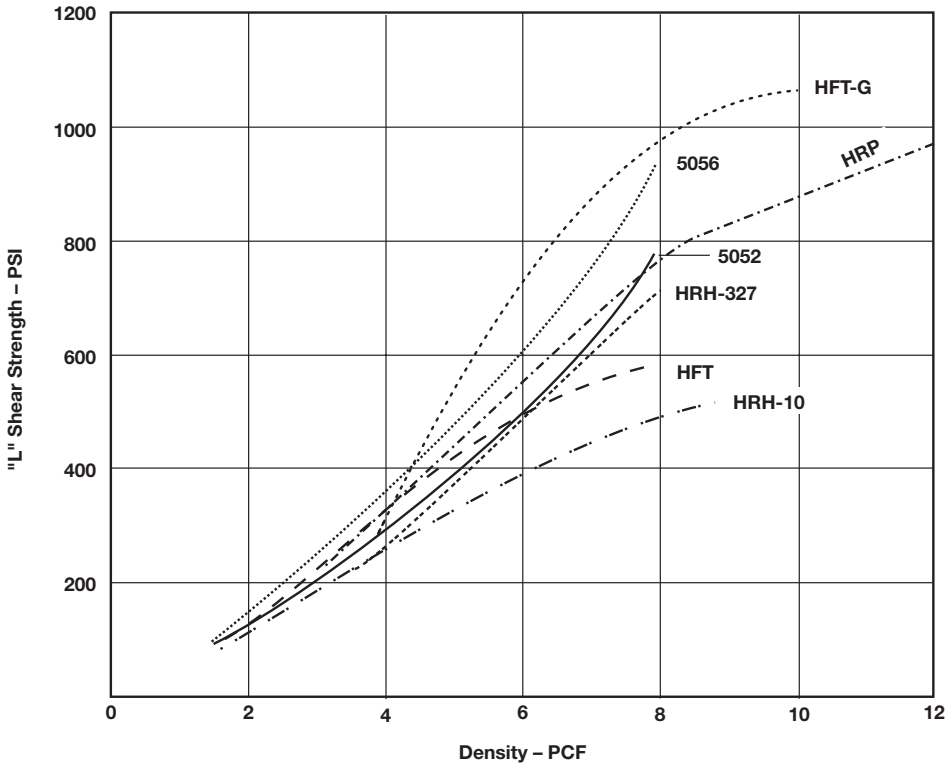
Typical Stabilized Compressive Strength



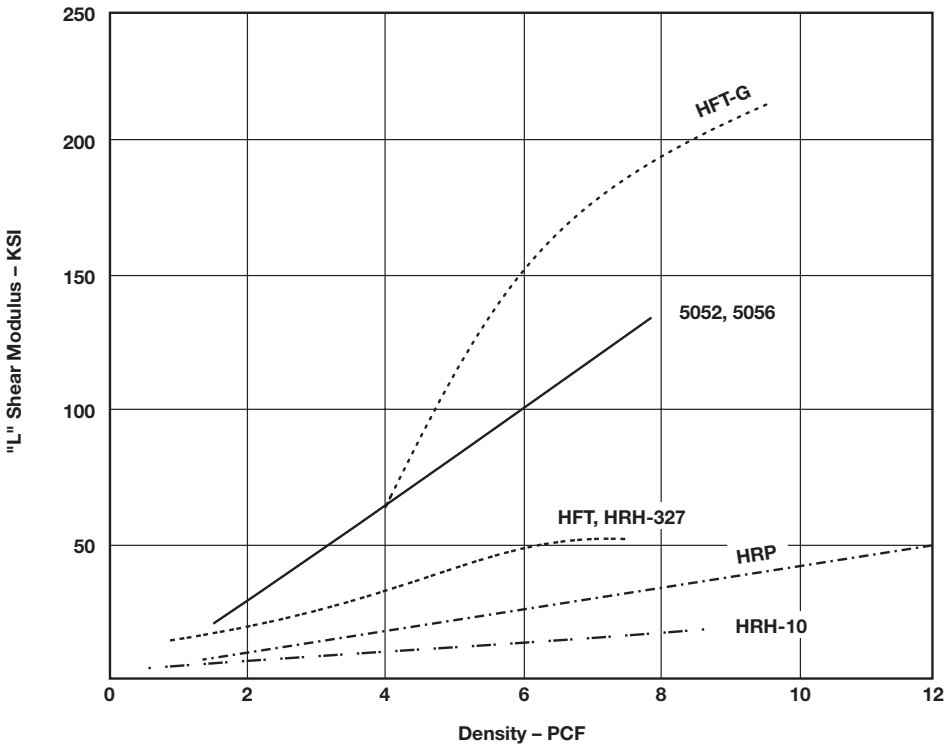
Typical Static Crush Strength



Typical L Shear Strength

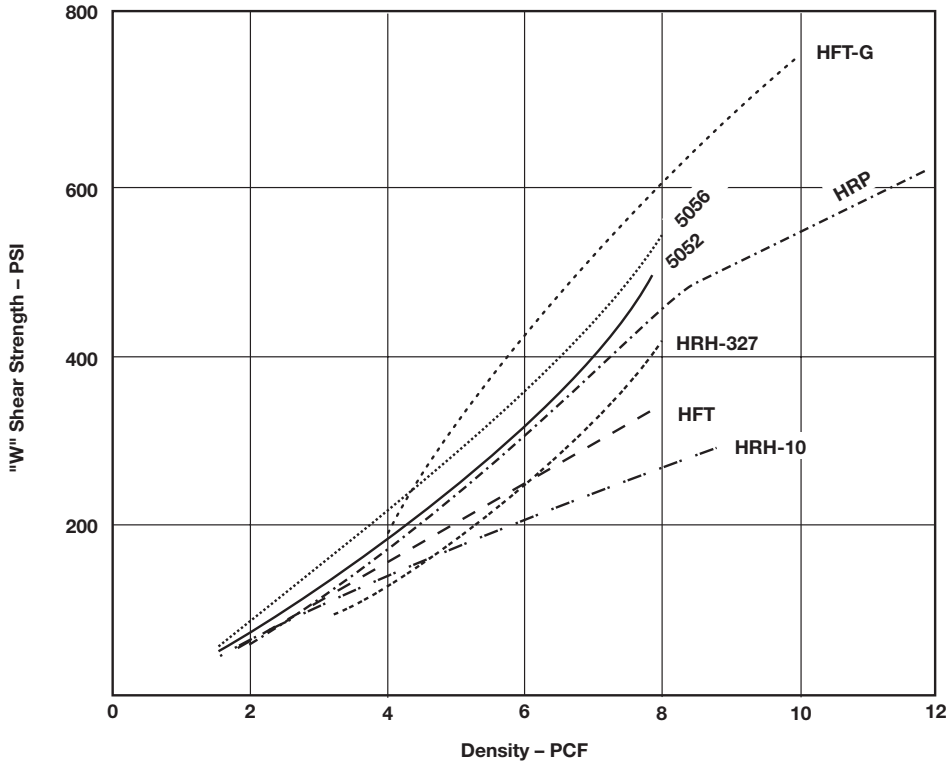


Typical L Shear Modulus

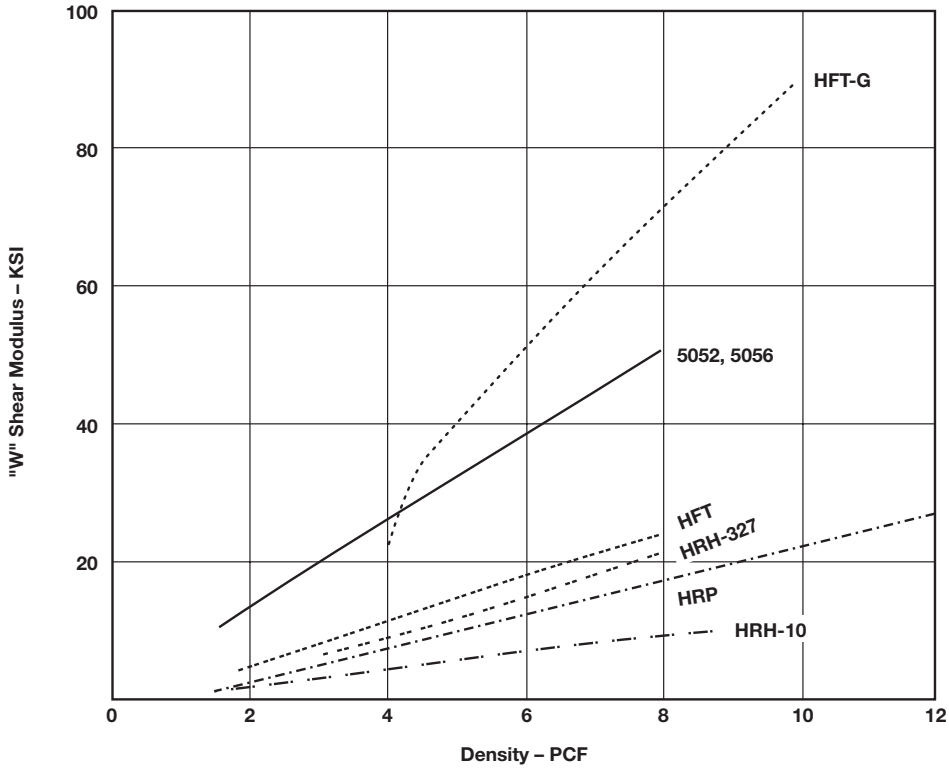


HEXCEL Composites

Typical W Shear Strength

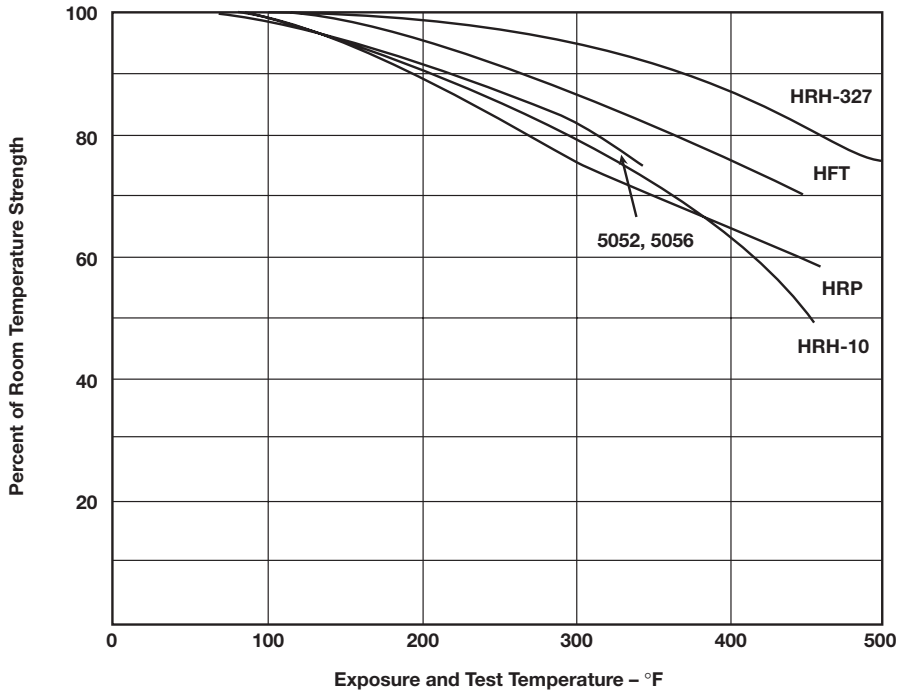


Typical W Shear Modulus

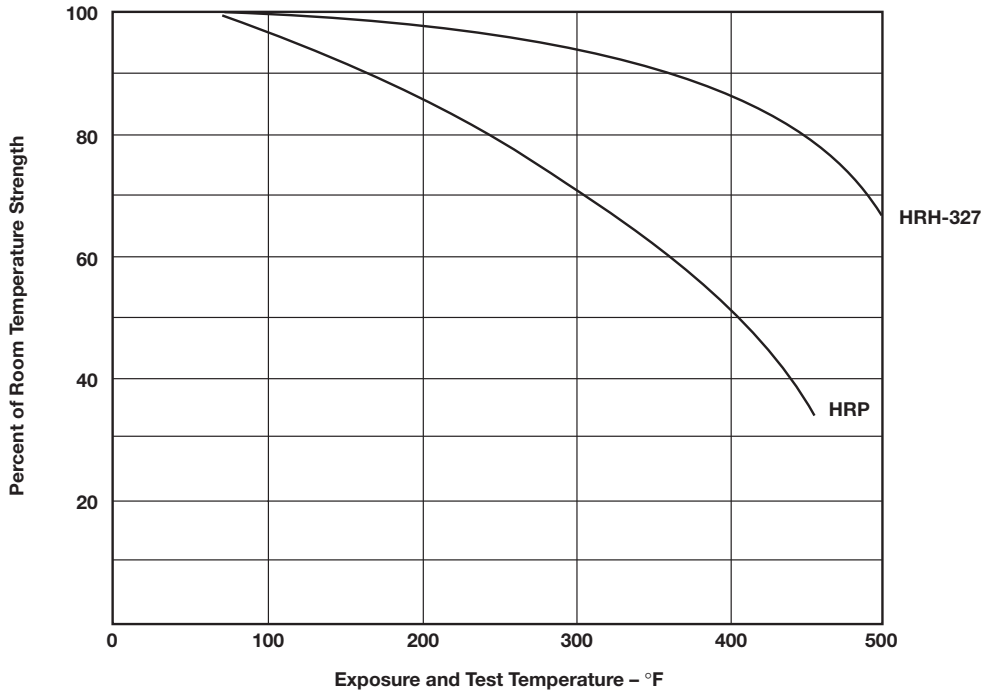


Temperature Effects

30-Minute Exposure (tested at temperature)



100-Hour Exposure (tested at temperature)



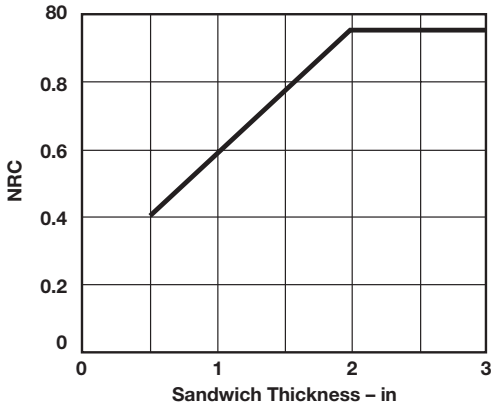
Additional Properties of Honeycomb

Acoustical

Honeycomb, to which a perforated facing skin has been applied, is often used for sound attenuation applications.

Hexcel's Acousti-Core honeycomb is filled with fiberglass batting. Available in many of the standard core types of 3/16" and larger cell size, this honeycomb with porous or perforated facings can be used for lightweight sound absorption panels that have considerable structural integrity.

Noise Reduction Coefficient



The noise reduction coefficient (NRC) of Acousti-Core is shown on the graph to the left. The NRC value is the average of sound absorption coefficients at 250, 500, 1000, and 2000 cycles per second. The higher the NRC value, the more efficient the absorber.

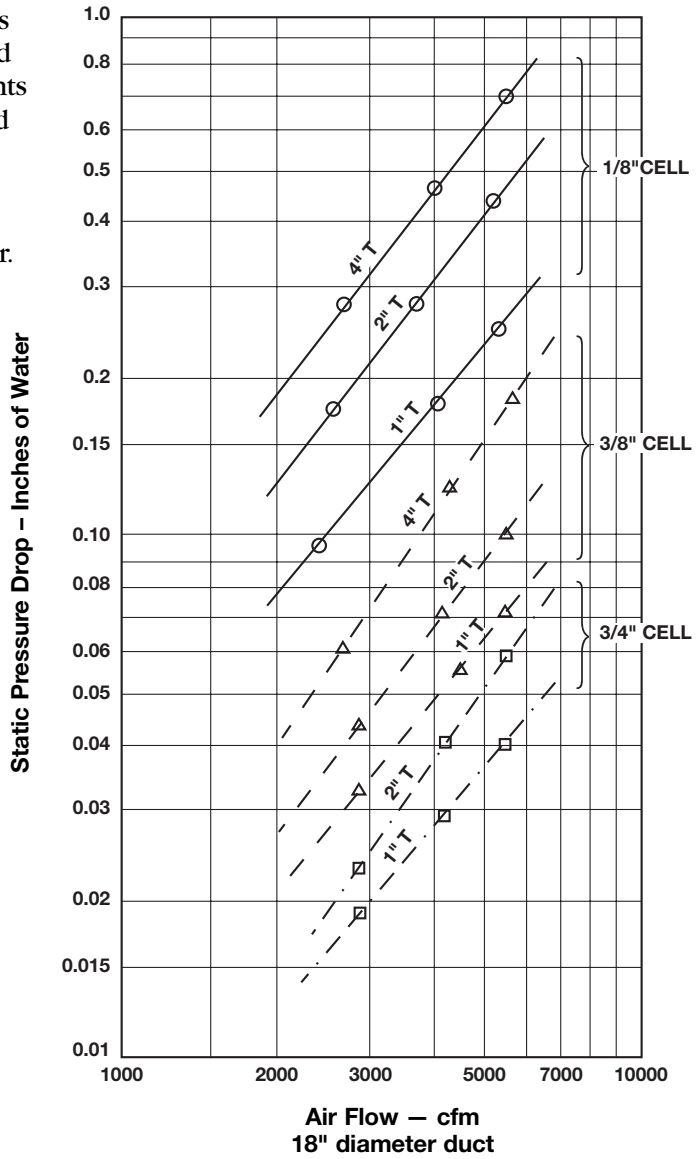
Air/Fluid Directionalization

Over the years, honeycomb has been used very successfully for directionalizing air, water, and fluid flow in a wide variety of ducts and channels. The open, straight honeycomb cells are an efficient means of controlling the flow of air with a minimum pressure drop. Laminar flow can typically be attained by using a honeycomb thickness to cell size ratio of 6–8 for most flow rates. Aluminum honeycomb with CR III corrosion-resistant coating is used for air directionalization applications.

Pressure Drop Across Honeycomb

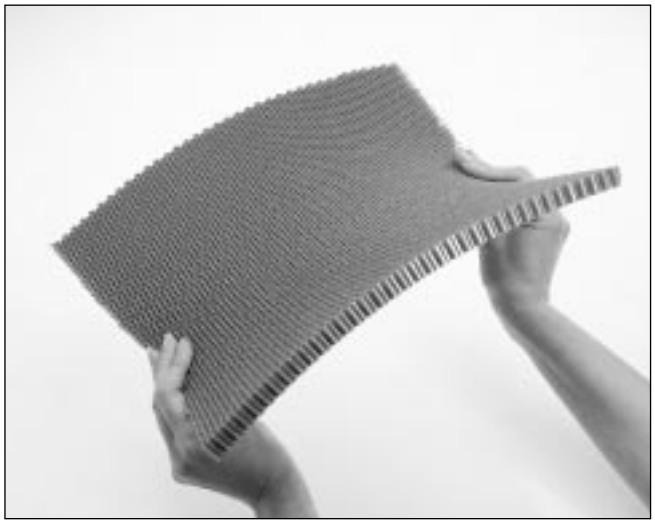
The pressure drop across honeycomb placed in a fluid stream has been found to be extremely small compared with alternate devices such as wire screens and perforated metal panels. The large open frontal area of honeycomb is the dominant reason for this. All honeycomb types considered for air directional applications have 95–99% open area. The major flow resistance is related to friction drag on the cell walls. As would be expected, smaller cell sizes and thicker honeycomb cores have higher pressure drops. The cell wall foil gauge has a negligible effect on the pressure drop. The figure at right shows the pressure drop measured across three aluminum honeycomb types at 1-, 2-, and 4-inch thickness. These measurements were made in a straight 18-inch diameter duct.

Pressure Drop Across Aluminum Honeycomb



Bending of Honeycomb

When hexagonal honeycomb is bent, it exhibits a phenomenon where the honeycomb is forcibly curved around one axis and the core reacts by bending in a reversed curvature along an axis oriented 90°. This phenomenon is called anticlastic curvature.



Poisson's ratio μ is the ratio of the lateral strain to the axial strain when the resulting strains are caused by a uniaxial stress. Poisson's ratios for different types of honeycomb have been determined to vary between 0.1 and 0.5. As would be expected, Poisson's ratio for Flex-Core cell configuration is less than Poisson's ratio for hexagonal cell configuration.

Coefficient of Thermal Expansion

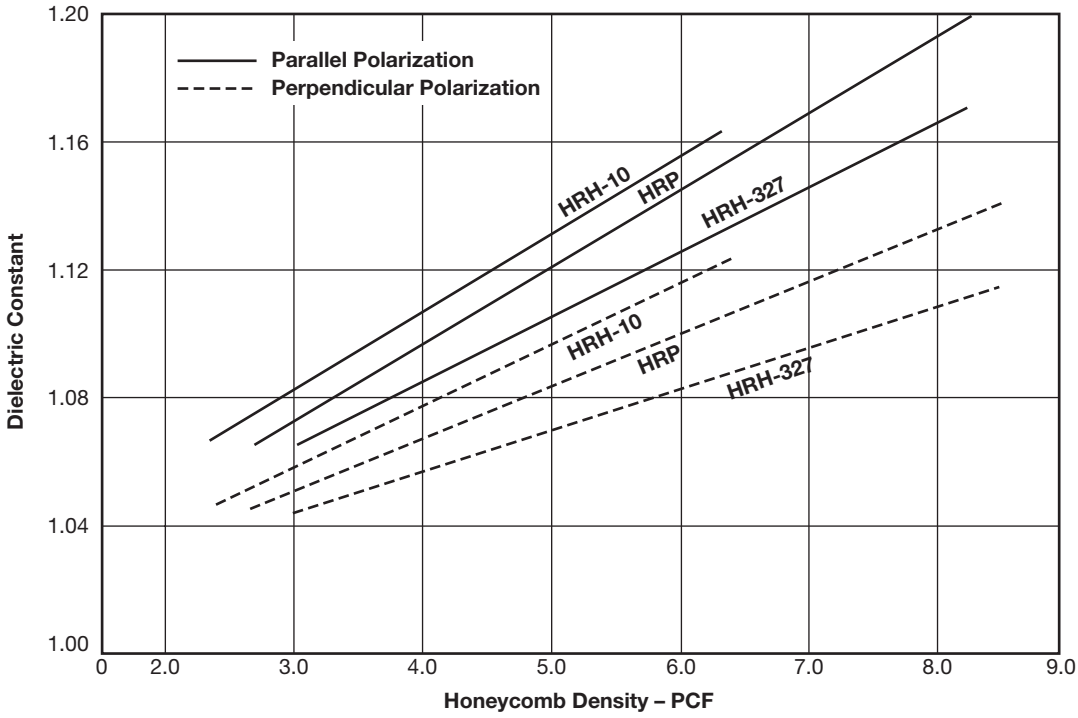
Honeycomb will change its dimensions slightly when subject to a change in temperature. The change in dimensions as a function of temperature is determined by the substrate material. Coefficients of thermal expansion in the thickness direction for various honeycomb materials are as follows:

Honeycomb Core	**Coefficient of Thermal Expansion** (inch/inch – °F)
CR III, CR-PAA, 5052, 5056, ACG Aluminum	13.2×10^{-6}
HRP, HFT, HRH-327 Fiberglass	8.2×10^{-6}
HRH-10, HRH-310, HRH-78 Nomex	19.4×10^{-6}
HRH-49 Kevlar	2.7×10^{-6}
HFT-G Carbon	2.0×10^{-6}

Dielectric

Nonmetallic honeycomb is used extensively in radomes, both airborne and stationary, because of its very low dielectric constant and loss tangent. Thus nonmetallic honeycomb allows the wave energy to be transmitted with only negligible reflection and absorption. The figure below shows the dielectric constant as a function of core density for several honeycomb types. The values were obtained for both polarizations and with the electric field vector E perpendicular and parallel to the ribbon direction. Testing was conducted at 9375 Megahertz. In addition to the electric field polarization, the dielectric constant is a function of the incidence angle and the thickness of the honeycomb.

Dielectric Constant at 0° Incidence Angle

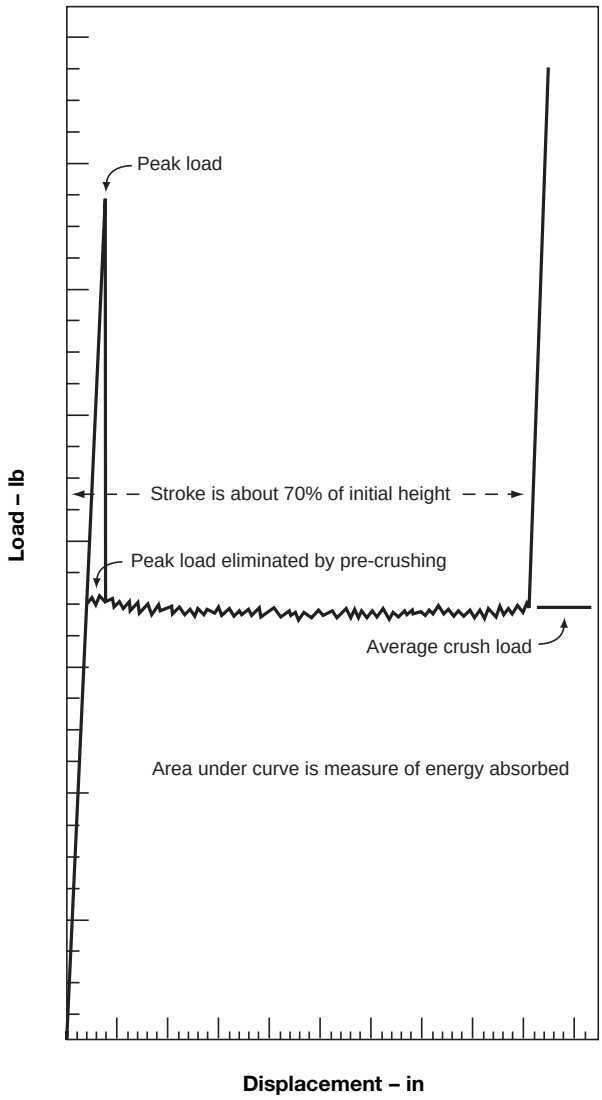


Energy Absorption

As mentioned under the Crush Strength property description (page 10), honeycomb loaded axially beyond its ultimate compressive peak will absorb energy at constant stress. The figure below shows the crush curve of aluminum honeycomb. Hexagonal honeycomb or Tube-Core used in this manner can be designed to crush uniformly at a predetermined level, thereby providing a highly reliable absorber at low weight.

See Hexcel technical brochure TSB 122, *Design Data for the Preliminary Selection of Honeycomb Energy Absorption Systems*, and the data sheet *Tube-Core Energy Absorption Cylinder* for further information on honeycomb for energy absorption applications.

Aluminum Honeycomb Crush Curve



Aluminum honeycomb absorbs energy by crushing under load.

Moisture Absorption

Samples of HFT, HRP, and HRH-10 were exposed to 95% relative humidity at 120°F for 120 hours to determine the moisture pickup. The following percent moisture pickups were measured.

HRP – 3/16 – 4.0	1.7%
HFT – 1/8 – 4.0	1.3%
HFT – 3/16 – 4.0	1.6%
HRH-10 – 3/16 – 4.0	4.4%
HFT-G – 3/16 – 6.0	2.0%
KOREX – 3/16 – 4.5	3.4%

Radio Frequency Shielding

Aluminum honeycomb has been used for RF shielding because the cellular structure can be compared to a myriad of wave guides. When properly designed as to cell size and cell depth, honeycomb will attenuate a required Db level through a wide frequency range.

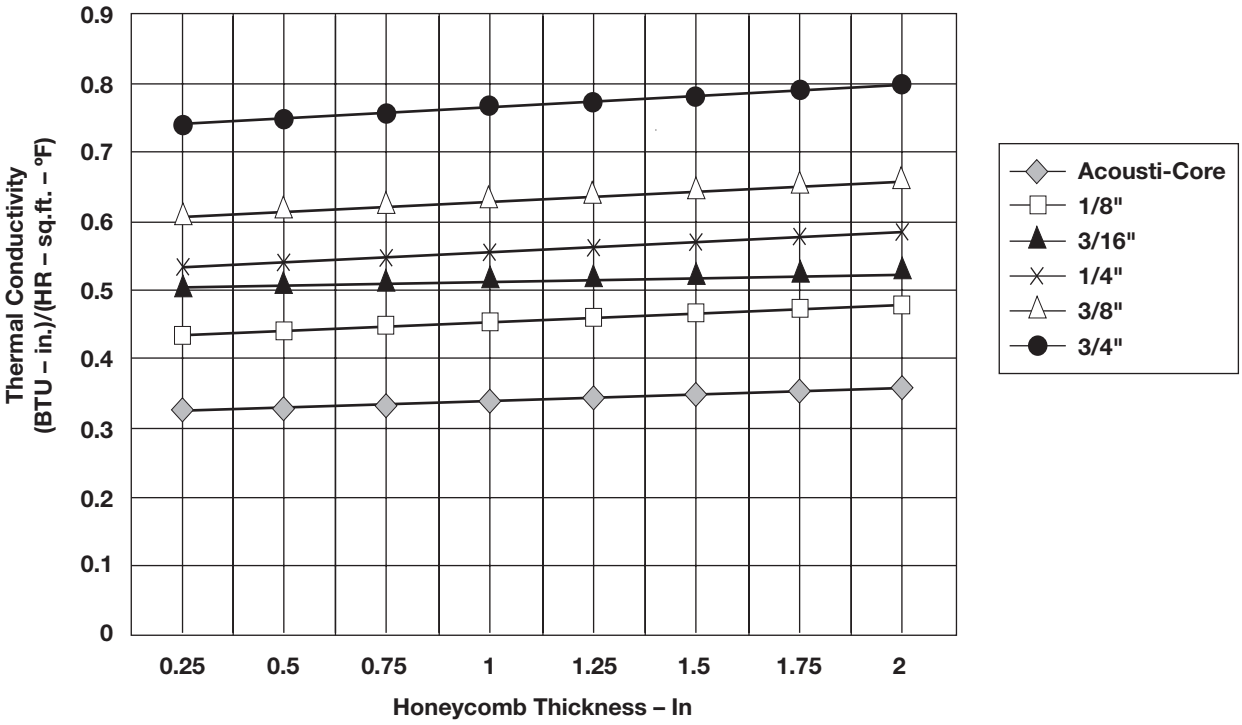
Thermal Conductivity

Thermal conductivity through sandwich panels can be isolated into the contribution of each component: facings, core, and adhesive. The resistances ($R = \frac{t}{k}$ or reciprocal of conductivity) can simply be added—including the effect of boundary layer conditions. The thermal properties of typical facing materials may be found in handbooks. Thermal resistance values for typical core-to-facing adhesives are 0.03 for film adhesives with a scrim cloth support and 0.01 for unsupported adhesives. The thermal conductivity of aluminum and nonmetallic honeycomb at a mean temperature of 75°F is shown below. For nonmetallic honeycomb, cell size is much more important than core density. For aluminum honeycomb, density is the variable that determines the thermal conductivity. The thermal conductivity of aluminum honeycomb is nearly independent of the core thickness, for thicknesses between 0.375–4.0". To adjust for mean temperature, multiply the thermal conductivity at 75°F by Q using the bottom figure. Thermal conductivity of honeycomb may be decreased by filling the cells with insulating materials.)

Thermal Conductivity of Aluminum Honeycomb

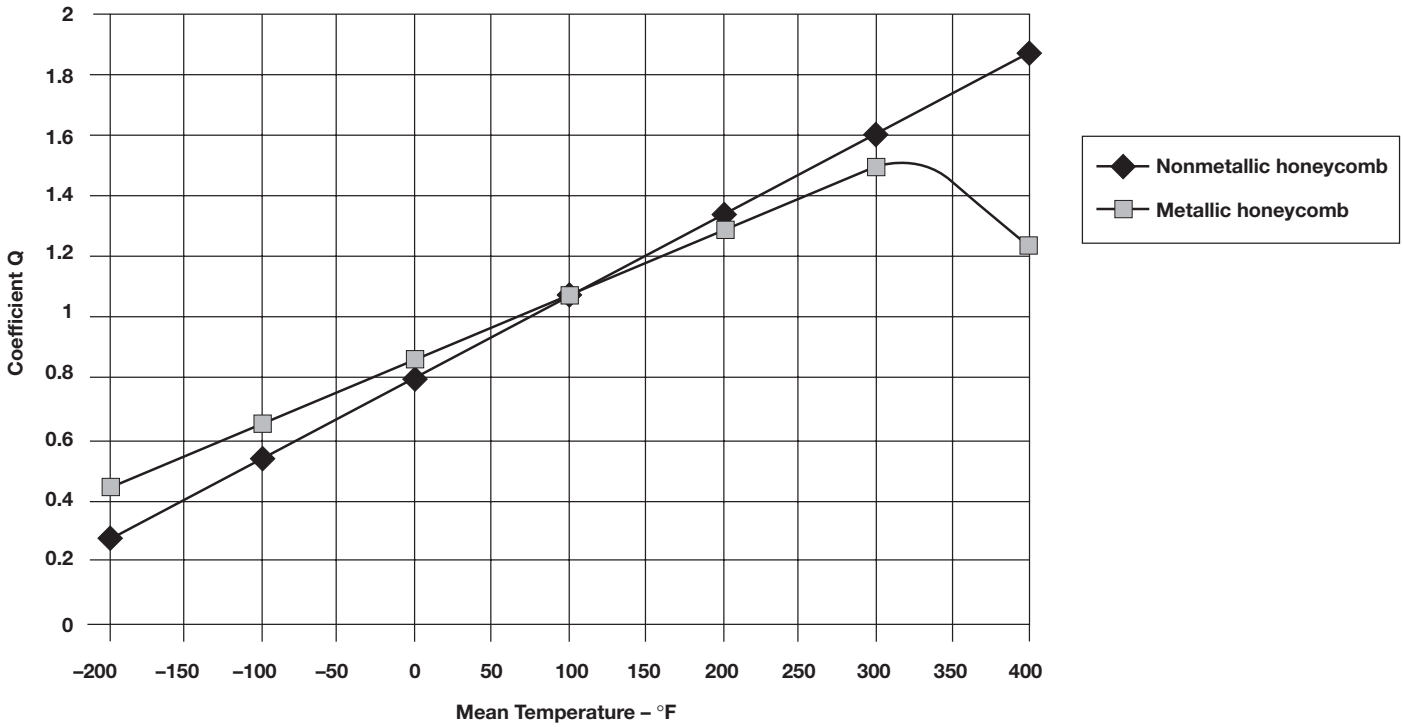
	Units				
Density	(lb/ft^3)	**2.0**	**4.0**	**6.0**	**8.0**
Thermal conductivity (k)	(BTU-in)/(hr-ft^2-°F)	27	38	61	103

Thermal Conductivity – Nonmetallic Honeycomb



Effect of Mean Temperature on Thermal Conductivity

$$k_T = k_{(75°F)} * Q$$



Comparison and Benefits of Honeycomb Versus Alternative Core Materials

Materials other than honeycomb are used as core materials. These are primarily foams and wood-based products. The advantages of honeycomb compared to these alternative core materials are as follows.

Material	Property	Honeycomb Advantages
Foam includes		
– polyvinyl chloride (PVC)	Relatively low crush strength and stiffness	Excellent crush strength and stiffness
– polymethacrylimide	Increasing stress with increasing strain	Constant crush strength
– polyurethane	Friable	Structural integrity
– polystyrene	Limited strength	Exceptionally high strengths available
– phenolic	Fatigue	High fatigue resistance
– polyethersulfone (PES)	Cannot be formed around curvatures	OX-Core and Flex-Core cell configurations for curvatures
Wood-based includes		
– plywood	Very heavy density	Excellent strength-to-weight ratio
– balsa	Subject to moisture degradation	Excellent moisture resistance
– particleboard	Flammable	Self-extinguishing, low smoke versions available

Sub-Panel Structure Comparison

The comparison at the right shows the relative strength and weight attributes of the most common types of sandwich panels.

	Relative Strength	Relative Stiffness	Relative Weight
Honeycomb	100%	100%	3%
Foam Sandwich	26%	68%	
Structural Extrusion	62%	99%	
Sheet & Stringer	64%	86%	
Plywood	3%	17%	100%

Applications

The major usage of honeycomb is for structural applications. Honeycomb's beneficial strength-to-weight and stiffness-to-weight ratios (see diagram on bottom of page 1) compared to other materials and configurations are unmatched.

Honeycomb's long-standing traditional application is in aircraft. Some of the aircraft parts that are made from honeycomb include:

- ailerons
- cowls
- doors
- elevators
- empennages
- fairings
- flaps
- flooring
- leading edges
- nacelles
- radomes
- rudders
- slats
- spoilers
- stabilizers
- struts
- tabs
- thrust reversers
- trailing edges

Other aerospace vehicles that use honeycomb include:

- helicopters
- missiles
- satellite launch vehicles
- satellites
- space shuttle

After aircraft and other airborne aerospace vehicles, the next most prominent uses for honeycomb occur in various land and water transportation vehicles. The different types of vehicles and most common applications are:

Automobiles

- energy absorption protective structures in Formula I race cars
- air directionalization for engine fuel injection system
- energy absorption in pillars and along roof line for passenger protection
- crash testing barriers

Rail

- doors
- floors
- energy absorbers/bumpers
- ceilings
- partitions

Marine

- commercial vessel and naval vessel bulkheads
- America's Cup sailing yachts
- wall, ceiling, and partition panels

Other applications for honeycomb that are not transportation related include:

- clean room panels
- exterior architectural curtain wall panels
- air, water, fluid, and light directionalization
- heating, ventilation, air conditioning (HVAC) equipment and devices
- skis and snowboards
- energy absorption protective structures
- electronic shielding enclosures
- acoustic attenuation

Hexcel Honeycomb Technical Literature Index

Brochures

- **Design Data for the Preliminary Selection of Honeycomb Energy Absorption Systems — TSB 122**
- **Hexcel CR-PAA™**
- **Hexcel Honeycomb FMVSS 201U Safety Standards**
- **Hexcel Special Process**
- **HexWeb™ Honeycomb Attributes and Properties**
- **Honeycomb Sandwich Design Technology**
- **Honeycomb Selector Guide**

Data Sheets

- **A1 and A10**. High Strength Aramid Honeycomb [U.K. manufactured equivalents to HRH®-10 and HRH®-78 respectively]
- **ACG® Honeycomb**. Aluminum Commercial Grade
- **Acousti-Core®**. Acoustical Absorption Honeycomb
- **Aluminum Flex-Core®**. Formable Aluminum Honeycomb
- **CFC™-20**. Composite Flooring Honeycomb Core
- **CR III®**. Corrosion Resistant Specification Grade Aluminum Honeycomb
- **CR III® Micro-Cell™**. Aluminum Honeycomb
- **CR-PAA™**. Phosphoric Acid Anodized Aluminum Honeycomb
- **CROSS-CORE®**. Bi-directional Aluminum Corrugated Honeycomb
- **Fibertruss® HFT®**. Fiberglass/Phenolic Honeycomb
- **Nonmetallic Flex-Core®**. Formable Nonmetallic/Phenolic Honeycomb
- **Hexcel Honeycomb in Air Directionalizing Applications**
- **HRH®-10**. Aramid Fiber/Phenolic Honeycomb
- **HRH®-49**. Honeycomb of Kevlar® 49
- **HRH®-78**. Nomex® Commercial Grade Honeycomb
- **HRH®-310**. Aramid Fiber/Polyimide Resin Honeycomb
- **HRH®-327**. Fiberglass Reinforced Polyimide Honeycomb
- **HRP®**. Fiberglass/Phenolic Honeycomb
- **KOREX®**. Para-Aramid/Phenolic Core
- **Rigicell™**. Corrosion Resistant Aluminum Corrugated Honeycomb
- **TPU™**. Thermoplastic Polyurethane Honeycomb
- **Tube-Core®**. Energy Absorption Cylinder
- **3003**. [U.K. manufactured equivalent to ACG®]
- **5052**. High Strength Aluminum Honeycomb [U.K. manufactured equivalent to CR III®]

Guide

- **Aluminum and Nomex® Honeycombs Cross Reference Guide**

Hexcel Composite Materials

For further information, please contact your nearest Hexcel Sales Office, or visit our web site at **www.hexcel.com**

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