HexWeb® Honeycomb Energy Absorption Systems

Design Data

HEXCEL®

Contents

Appendix

Bibliography

This listing presents some of the basic publications on the development and use of HexWeb® energy absorption systems. Many additional references are presented in the bibliographies of these publications.

Summary reports on the energy absorbing characteristics of aluminum, plastic, and paper honeycomb:

Karnes, Charles H., Turnbou, James W., et al, High Velocity Impact Cushioning, Part V, Energy-Absorption Characteristics of Paper Honeycomb, Structural Mechanics Research Laboratory, University of Texas, Austin, Texas, March 25, 1959.

McFarland, R.K., The Development of Metal Honeycomb Energy-Absorbing Elements, Technical Report No. 32-639, Jet Propulsion Laboratory, Pasadena, California, July 1964.

RF Transparent, Energy Absorbing, Structural Elements. Phase 1, Final Report to JPL from General Electric, G.E. Document 64 SD 565. Schenectady, N.Y., 1964

McFarland, R.K., Hexagonal Cell Structures Under Post-Buckling Axial Load, AIAA Journal, Vol. 1, No. 6, June 1963.

Energy Absorbing Characteristics of Several Materials, Report SCTM 284-57 (51), Sandia, Livermore, California, 1960.

Honeycomb Technology, Tom Bitzer, Chapman & Hall, London, UK, 1997.

General references on the analytical and experimental aspects of shock measurement:

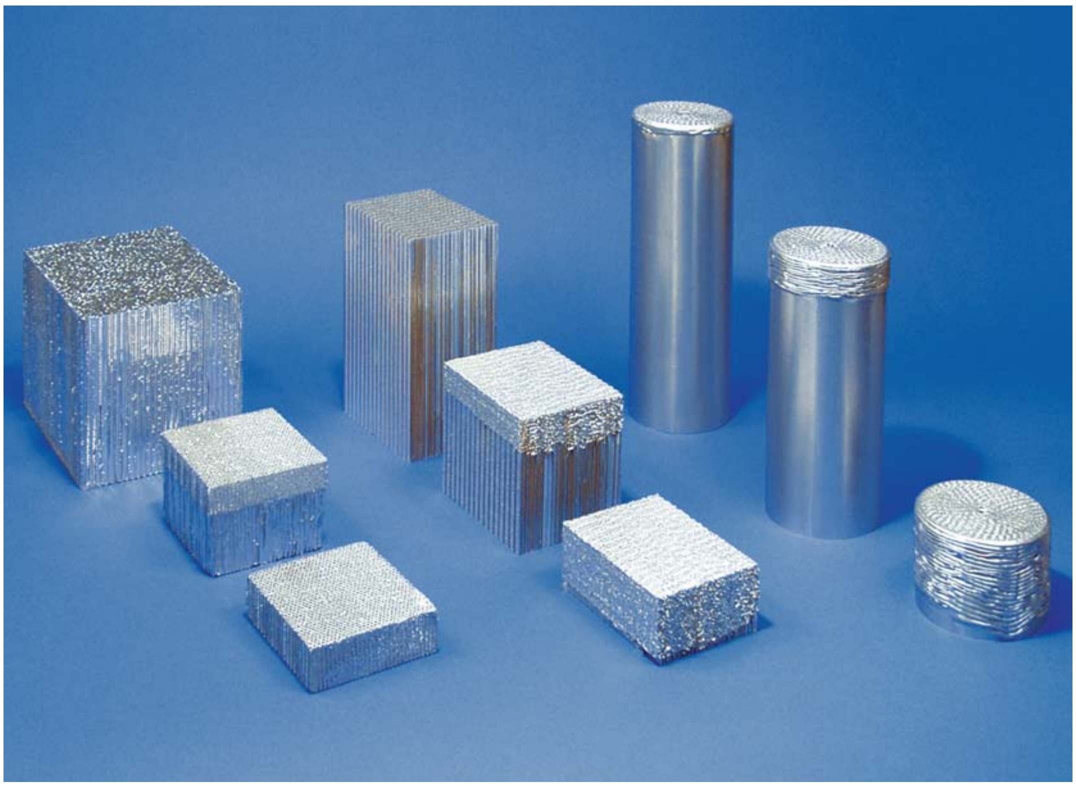
Dove, R. C. Adams, P.H., Experimental Stress Analysis and Motion Measurement, Charles E. Merrill Books, Inc., Columbus, Ohio, 1964.

Jacobsen, L.S., Ayre, R.S., Engineering Vibrations, McGraw-Hill Book Company, New York, 1958.

Porter, John H., Utilizing the Crushing Under Load Properties of Polypropylene and Polyethylene Honeycomb to Manage Crash Energy, Society of Automotive Engineers, Inc., 1994.

Introduction

This manual presents methods for designing HexWeb® honeycomb energy absorption systems. The different HexWeb® cores and their properties are discussed, and the basic design equations are given. Two solved example problems are also included.



Honeycomb absorbs energy by crushing under load. This characteristic has proven to be one of the most reliable and efficient methods of providing "G" limit protection.

The action of crushing under load develops a uniform level of stress near the optimum response desired for energy absorption materials. HexWeb® honeycomb has found application in:

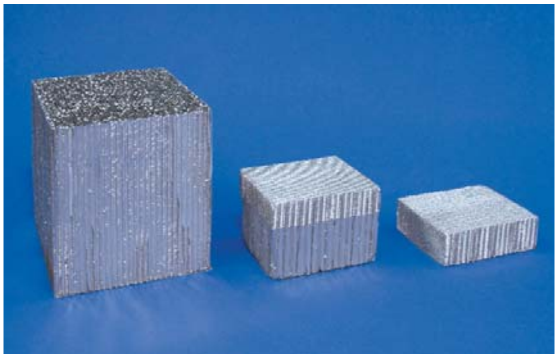
- FMVSS 201 U rollover countermeasure pads
- Load and "G" limit barriers
- Single event protective pads

Hexcel supplies HexWeb® as energy absorbing raw material or discreet components. Please contact your Hexcel representative for more information.

HexWeb® Honeycomb Types

Energy absorption systems usually use corrosion resistant CRIII® or CR-X® aluminum, but HRP® fiberglass and HRH-10® honeycombs have also been used successfully. All three types crush at about 50 percent of their bare compressive strengths (The *HexWeb® Honeycomb Attributes and Properties* brochure gives honeycomb static crush strengths. Some crush strengths are also given on page 16 of this document). HexWeb® honeycomb crushes by the cell walls buckling and folding over, while fiberglass cores crush by the cell walls actually breaking. The stroke (distance the honeycomb is crushed) is from 55 to 80 percent of the honeycomb thickness for the aluminum and HRH-10® honeycomb and between 70 to 85 percent for the fiberglass honeycomb. The percentages vary with honeycomb density; i.e., the lower the density the longer the stroke.

There are three cell constructions consisting of the Standard HexWeb® Honeycomb, Tube-Core® and Cross-Core®.

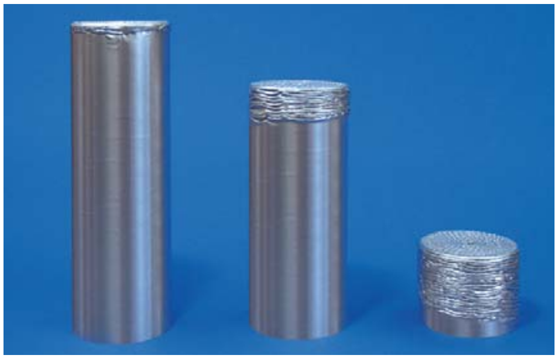


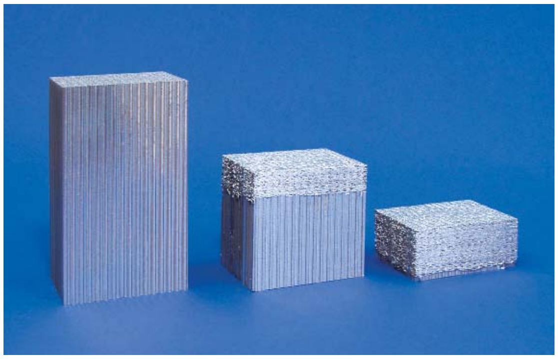
Standard HexWeb® Honeycomb

Manufactured by both the corrugated and expanded method, this configuration is widely used for general energy absorption problems. Aluminum, reinforced plastic, and paper are the more common materials used in making these core materials. The standard hexagonal product can be over-expanded or under-expanded to vary its density and crush strength.

Tube-Core®

Tube-Core® has corrugated and flat sheets wrapped around a mandrel. Designed in aluminum for efficient energy absorption where the spacing requires a thin-wall annular column or small diameter cylinder, Tube-Core® eliminates the loss of crush strength at the edges, an inherent characteristic of standard core when used in small diameter cylinders.





Cross-Core®

Manufactured in various selected cell axis orientations, foil gages, aluminum alloys, and corrugation heights, Cross-Core® offers a multi-directional energy absorption system to suit many design situations.

Typical HexWeb® Crush Curve

The HexWeb® honeycomb crush strength test consists of taking a 3 in. (75 mm) by 3 in. (75 mm) specimen with a thickness of 1 in. (25 mm) or greater, precrushing one side, then testing in a test machine with a fixed head at a 1 in. (25 mm) per minute loading rate. The load-deformation curve is obtained from the cross-head travel. The average crush load is divided by the initial cross-sectional area to obtain the static crush strength. If the core is not precrushed, the specimen fails initially at the bare compressive strength, then begins to crush. The definitions of some terms are given below.

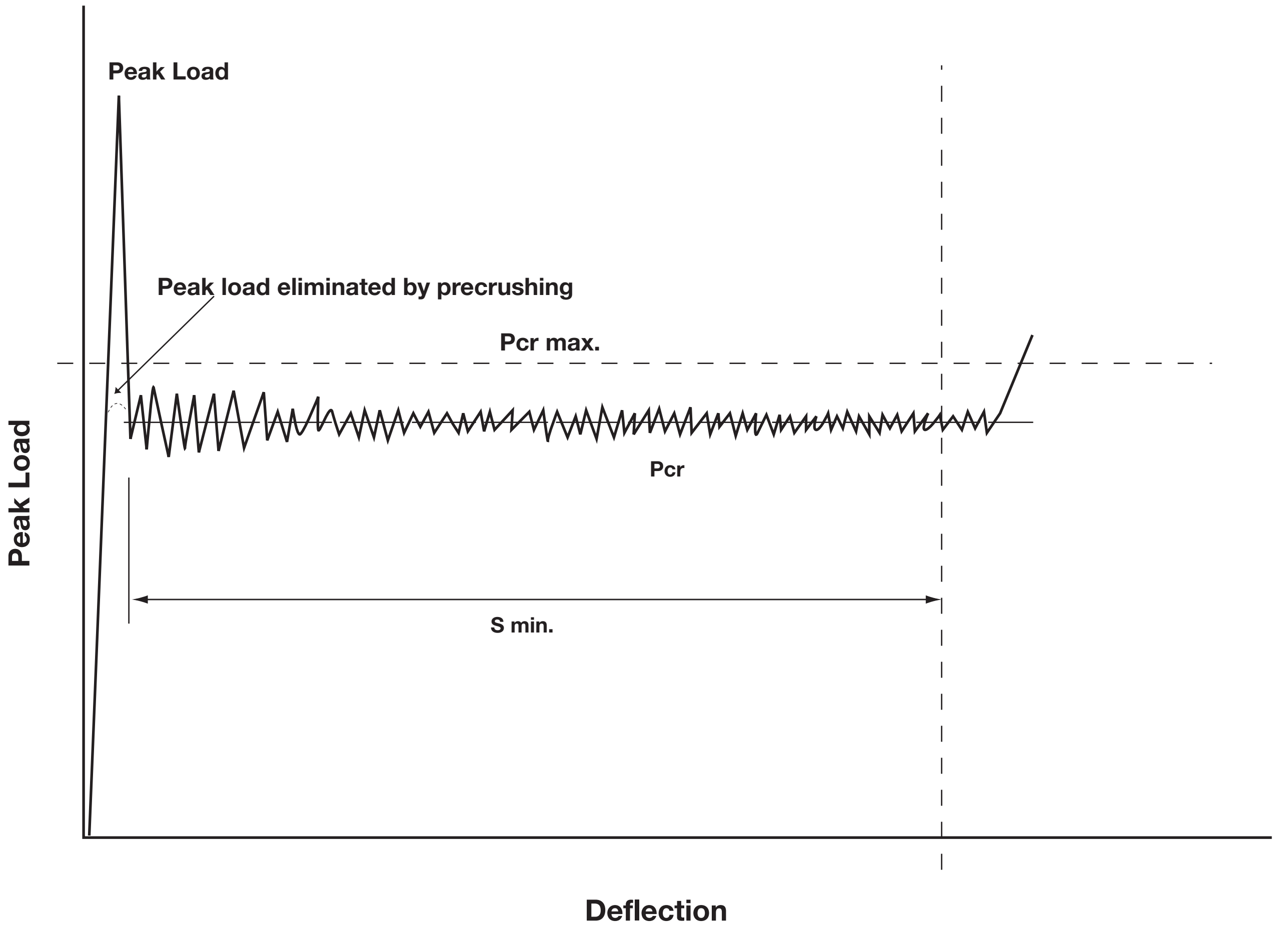
Glossary of Terms

Peak Load	The honeycomb bare compressive strength (specimen not precrushed).
Precrushing	Prefailing the honeycomb cell walls to eliminate the peak load. Can be accomplished by precrushing the honeycomb.
Stroke	The thickness of honeycomb crushed, usually between 55% to 80% of the initial height.
Minimum Stopping Distance	The vertical dashed line drawn down **Figure 1** represents a hypothetical stopping distance minimum established in conjunction with the maximum crush level value. This value represents a minimum value for the maximum crush level line and any crush level selected below the maximum limit will require an increase in this minimum thickness.
Average Crush Load	The average of the peaks and valleys of the crush load, P_{cr}. The peaks and valleys of aluminum and aramid honeycomb are caused by the cell walls buckling and then folding over themselves.
Maximum Crush Level	A horizontal line has been drawn across the curve in **Figure 1** representing a maximum crush level. If this hypothetical line had been developed as a design maximum, then the actual honeycomb piece P_{cr} value must remain equal to or below this level, P_{cr} maximum for crushing to take place.
Bottomed Out	When the honeycomb is fully crushed to a solid piece, and the load drastically increases. Note: fiberglass honeycomb is just a quantity of resin and broken fiberglass after being crushed.
Energy Absorbed	The energy used in crushing the honeycomb. Calculated as the area under the load-deformation curve, usually P_{cr} times S.
Rebound	After aramid honeycomb is fully crushed, it will regain some of its thickeness.

Crush Strength Curve

HexWeb® honeycomb has the unique property of crushing in a uniform, predictable, and efficient manner. It is very reliable and lightweight, thus it is well adapted for energy absorption applications. A typical honeycomb crush strength curve is shown and explained below in **Figure 1**.

Figure 1

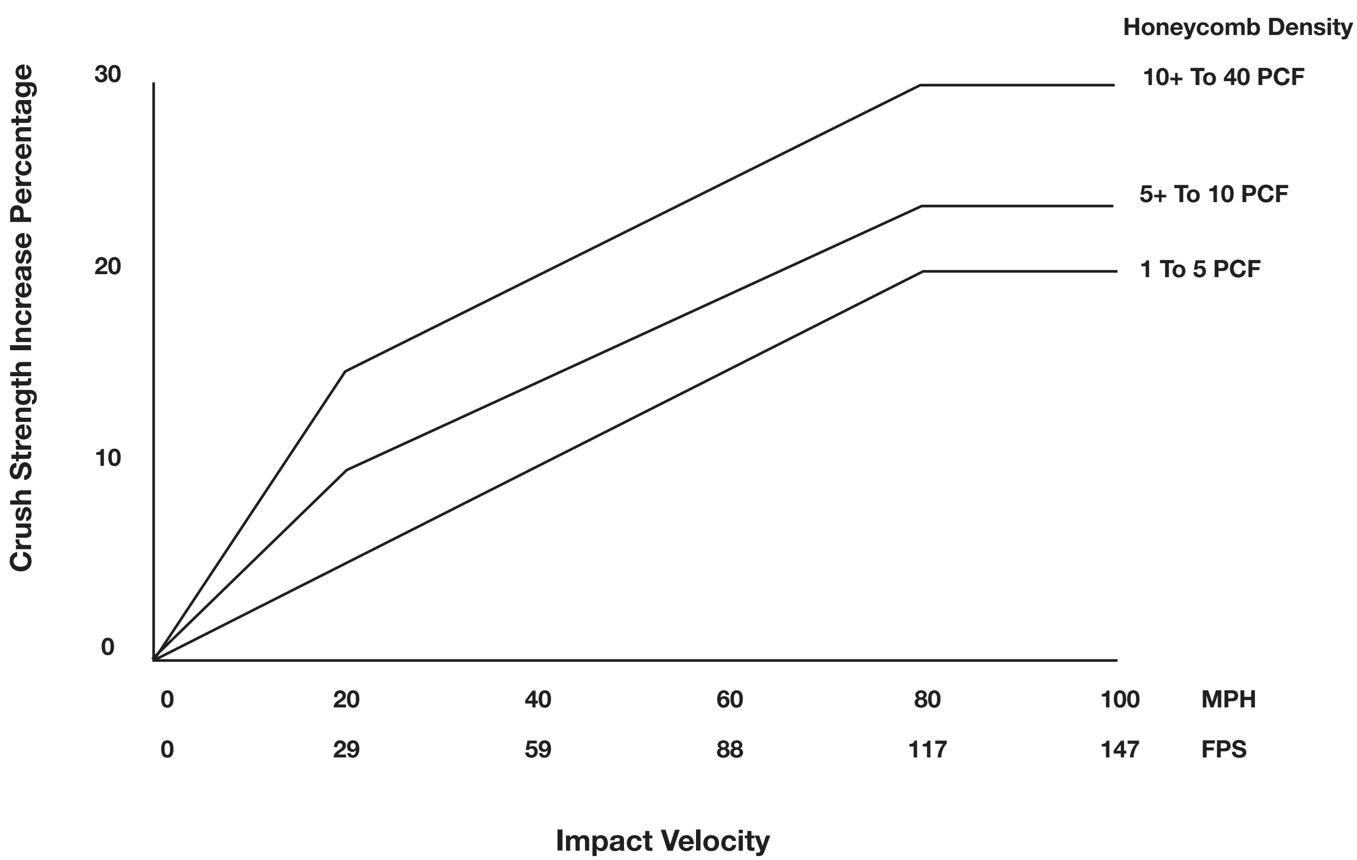


Dynamic Crush Strength Guideline

The speed at which the impact object hits the honeycomb does have an effect on the honeycomb crush strength. The dynamic crush strengths are greater than the static strengths, and are a function of the honeycomb density and impact velocity. The denser the honeycomb and the faster the impact velocity, the higher the crush strength. **Figure 2** has some guidelines for increasing the static crush strengths for designing energy absorption systems.

Figure 2

(Just a guide: Core should be tested under actual conditions)

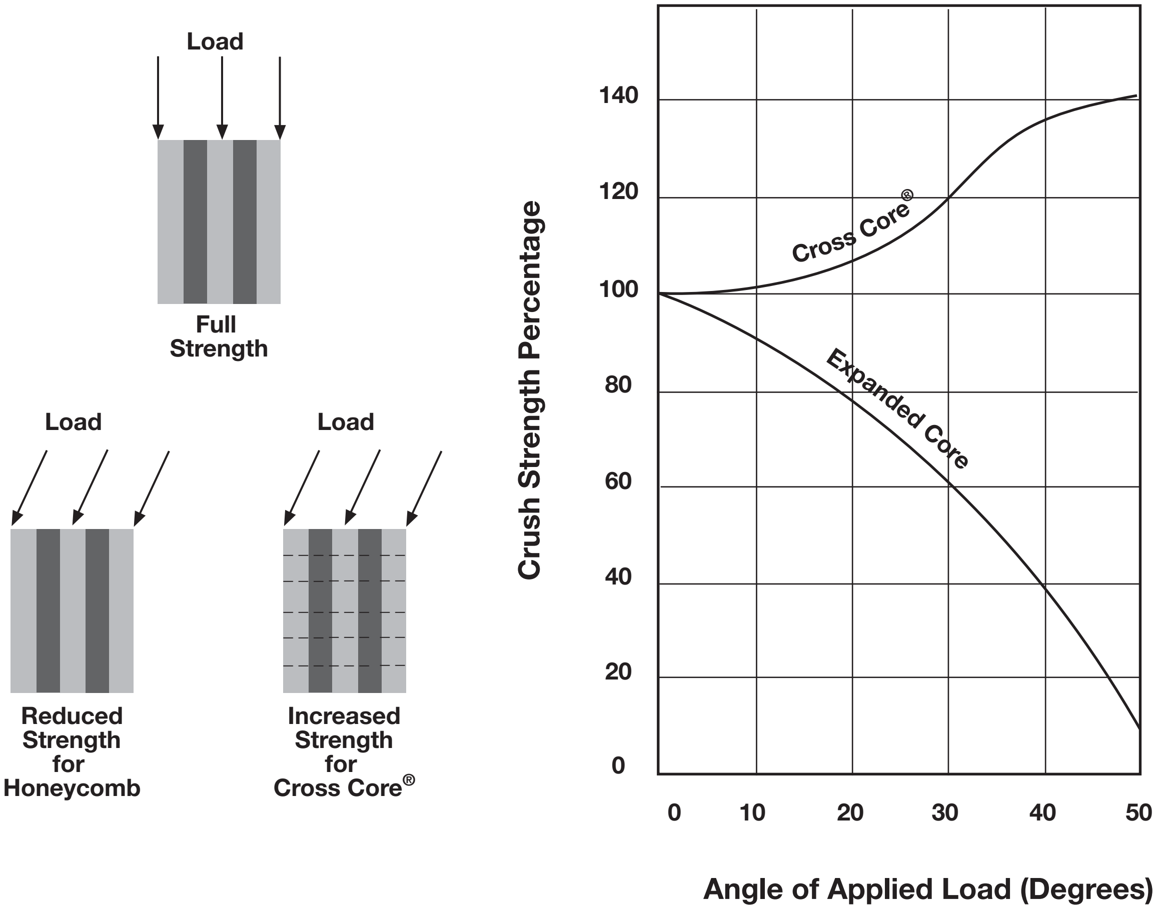


Load Angle Effect on Crush Strength

HexWeb® honeycomb absorbs energy best when the load hits parallel to the cell axis or normal to surface. If the load hits an angle, the honeycomb's efficiency goes down - see **Figure 3**.

Figure 3

(Just a guide: Core should be tested under actual conditions)



Complex Geometry Crush Strength Curve

Many situations place honeycomb in contact with impact surfaces other than parallel planes. In these cases the geometry can remove the peak compressive load. This can eliminate the need to precrush. A representative curve is presented below in **Figure 4**. The shape of the curve can be developed analytically or empirically. Your Hexcel representative can provide more information.

Figure 4

Impact Event

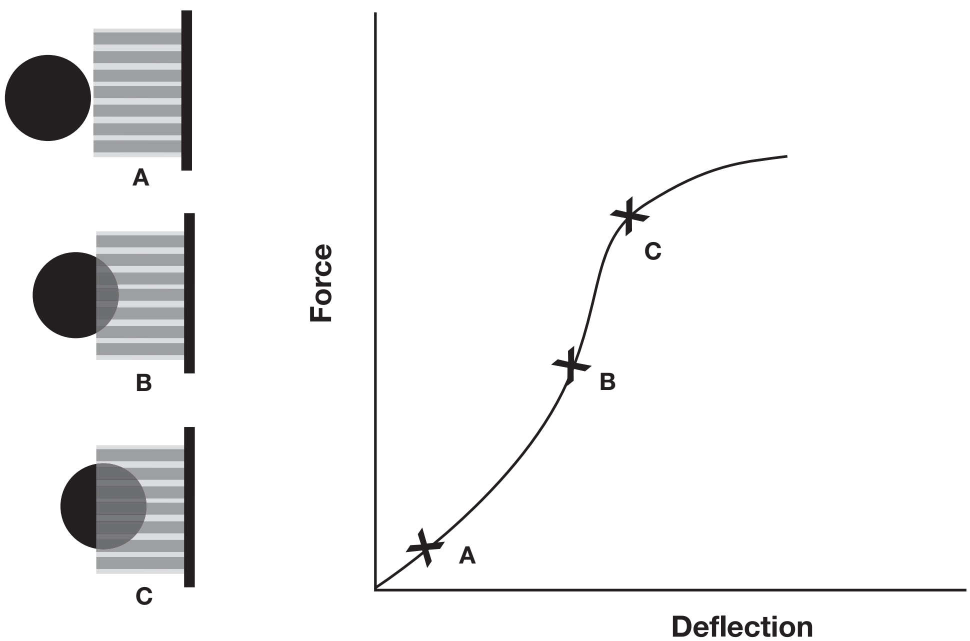


Figure 5

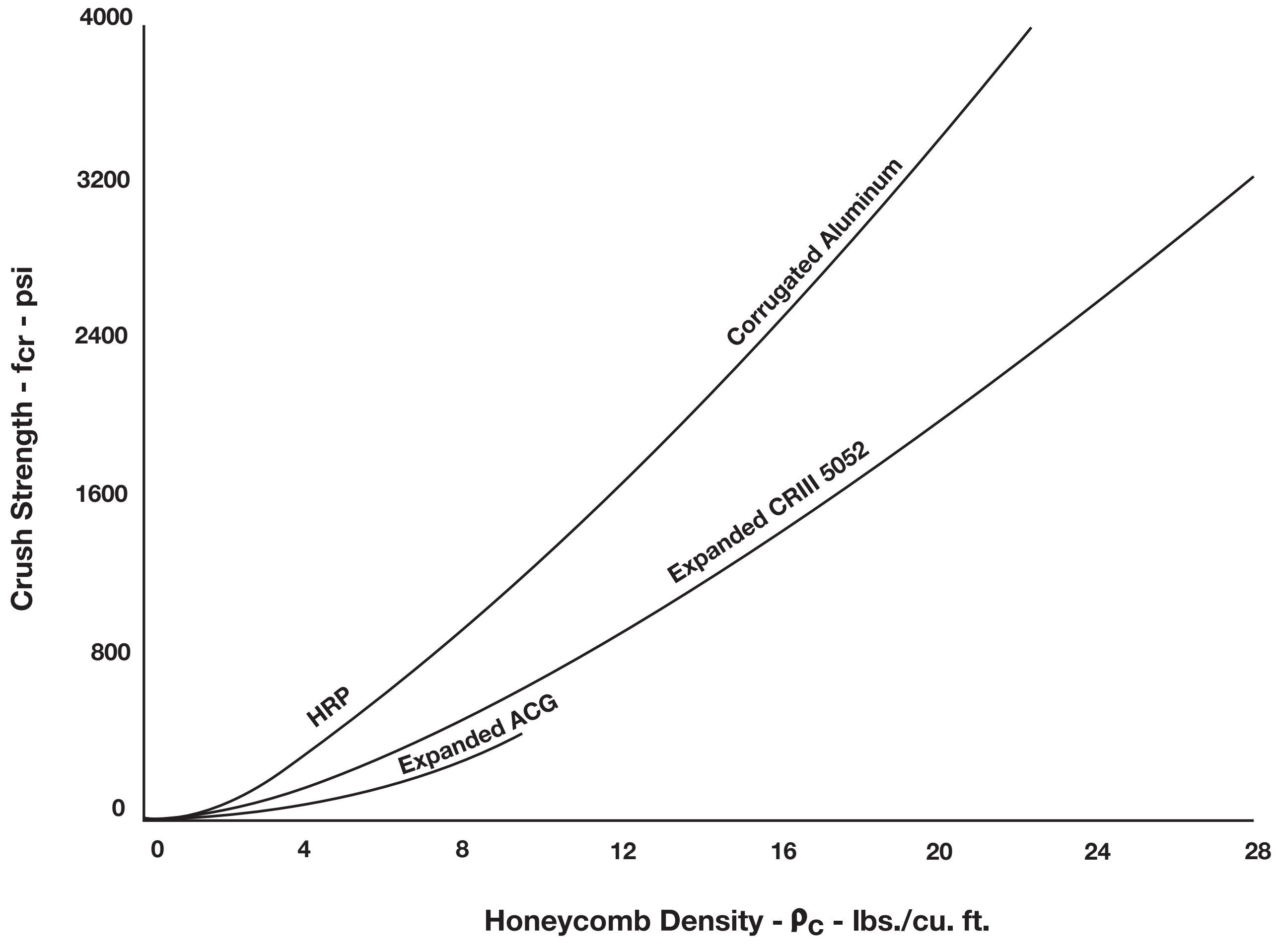
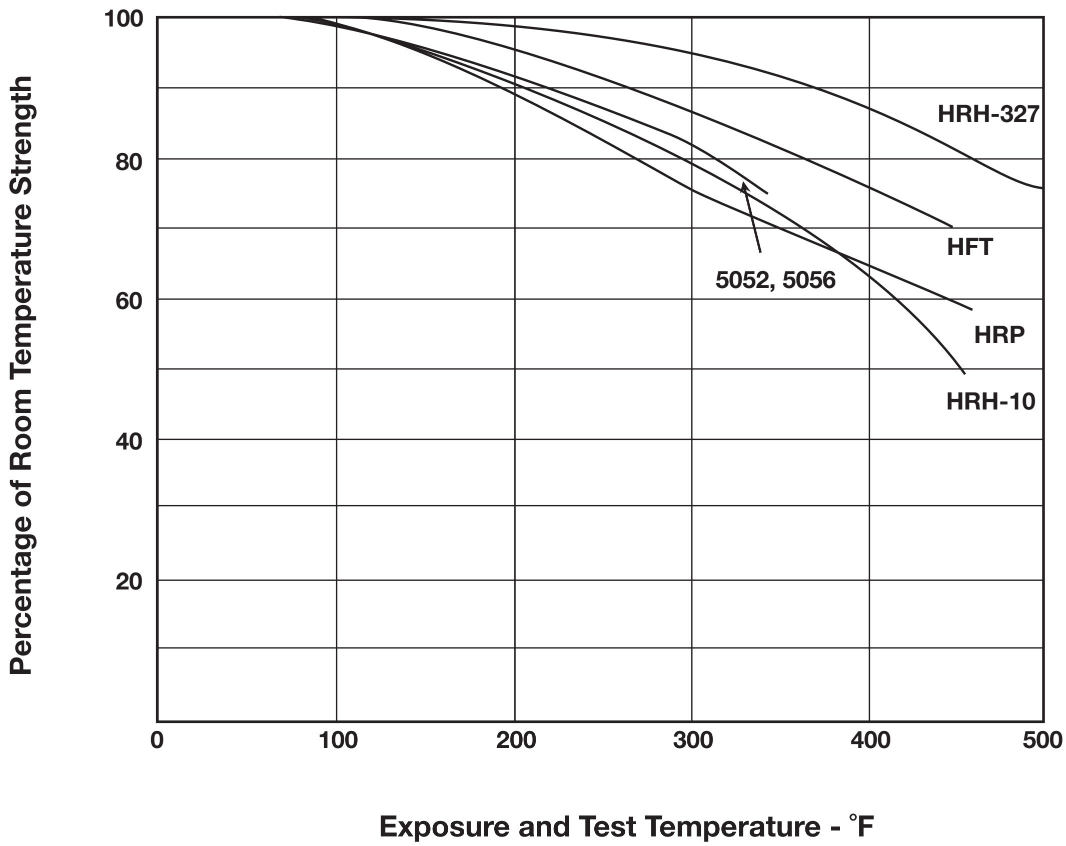

Crush Strength - fcr - psi
4000
3200
2400
1600
800
0
0
4
8
12
16
20
24
28
Honeycomb Density - ρc - lbs./cu. ft.
Corrugated Aluminum
Expanded CRIII 5052
HRP
Expanded ACG

Figure 6

Temperature Effects

30-Minute Exposure (tested at temperature)



Symbols

	Measurement	Metric	
A_{cr}	in^2	mm^2	Crushed impact area
a	ft/sec^2	m/sec^2	Acceleration or deceleration rate
F_{dyn}	lbs	kg	Dynamic impact force
f_{cr}	psi	kPa	HexWeb® crush strength – average load/initial area
F_{static}	lbs	kg	Impact object weight
g	ft/sec^2	m/s^2	Acceleration due to gravity
G	—-	—-	Ratio a/g
h	ft	m	Drop height
K_s	—-	—-	Stroke efficiency factor - assumed to be 70% - actual results vary.
m	slugs	kg	Mass
ρ_c	pcf	kg/m^3	HexWeb® core density
P_{cr}	lbs	kg	Average static crush load (ref. energy absorbed, next page)
s	feet	m	Stopping distance, HexWeb® crush stroke
t	seconds	seconds	Time
T_c	inches	mm	Honeycomb core thickness
V_o	ft/sec	m/s	Initial velocity
V_f	ft/sec	m/s	Final velocity
W	lbs	kg	Impact object weight

Design Procedures

A suggested energy absorption design procedure is as follows:

	Vertical	Horizontal
Determine the stroke required to limit the G load to the allowable level.	$G = \frac{h + s}{s}$ thus $s = \frac{h}{G-1}$	$G = \frac{V^2}{2gs}$ thus $s = \frac{V^2}{2gG}$
Determine the energy that must be absorbed.	$PE = W(h + s)$	$KE = \frac{1}{2}\frac{W}{g}V^2$
Determine the dynamic force, $F_{dyn} = f_{cr}A_{cr}$	$W(h + s) = f_{cr}A_{cr}s$ $\frac{1}{2}\frac{W}{G}V^2 = f_{cr}A_{cr}s$	$F_{dyn} = \frac{W(h + s)}{s}$ $F_{dyn} = \frac{WV^2}{2gs}$
Determine impact velocity.	$V = \sqrt{2gh}$	given velocity

Select a HexWeb® and area to satisfy the dynamic force.

Note: The designer must increase the static crush strength for the dynamic effect which is a function of HexWeb® density, ***Figure 5****, and impact velocity,* ***Figure 2****. It may be necessary to adjust the crush strength for temperature environment,* ***Figure 6****.*

Determine total honeycomb thickness.

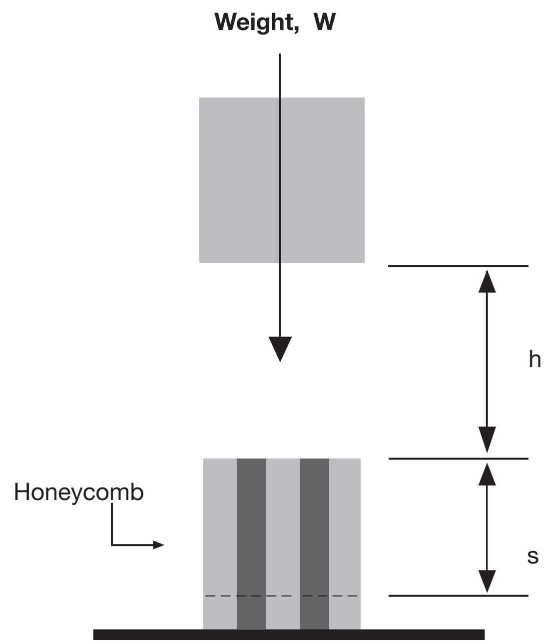
Use as example for formula K_S = stroke factor (assume 70%)

$T = \frac{\text{s (stroke required) + precrush}}{K_S}$ $\qquad$ $T = \frac{\text{s (stroke required) + precrush}}{\text{stroke efficiency}}$

Precrush note: Usually about 1/8 to 1/4 inch

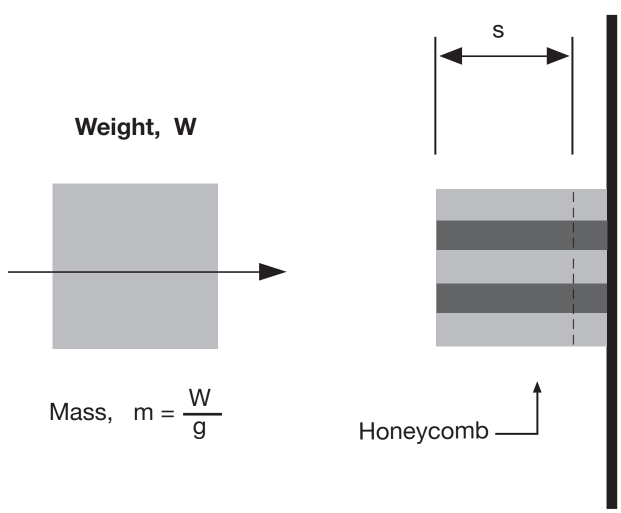
Kinetic Energy,	$KE = \frac{1}{2} mV^2$
Potential Energy,	$PE = mgh$
Mass,	$m = \frac{W}{g}$
Dynamic Force,	$F = ma$ or $F = GW$
"G" Load,	$G = \frac{a}{g}$ or $G = \frac{F_{dyn}}{F_{static}} = \frac{F_{dyn}}{W}$
Earth's Gravitational Constant,	$g = 32.2\ ft/sec^2$ or $9.8\ m/sec^2$
Velocity,	$V_f = V_o + a_t$
Velocity,	$V_f^2 = V_o^2 + 2as$
Velocity falling object,	$V = \sqrt{2\,gh}$

EXTERNAL ENERGY		INTERNAL ENERGY
$W(h+s)$	=	$f_{cr}A_{cr}s$
"G" Load	=	$\frac{h+s}{s}$
$V_{AT\ IMPACT}$	=	$\sqrt{2gh}$



Vertical Drop Equations

EXTERNAL ENERGY		INTERNAL ENERGY
$\frac{1}{2} m V^2$	=	$f_{cr}A_{cr}s$
"G" Load	=	$\frac{V^2}{2gs}$



Horizontal Motion Equations

Vertical Drop Energy Absorption Example

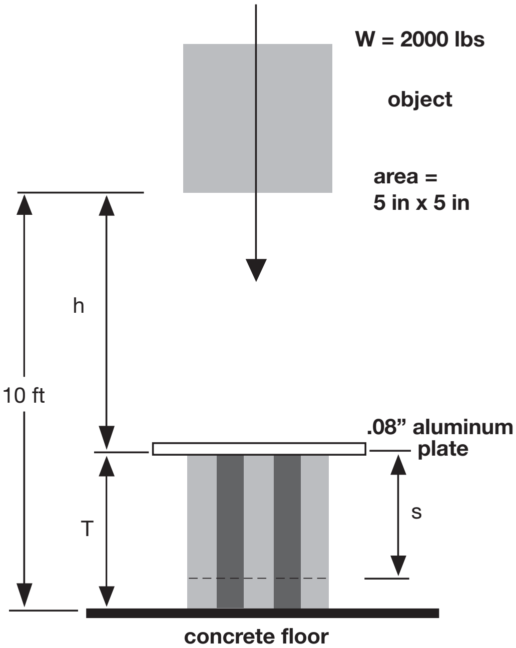
Vertical Drop

Situation:

A 2,000 pound weight is 10 feet above a concrete floor and could fall. The floor can only withstand a 16,000 pound dynamic force.

Problem:

Protect the floor.



Calculations:

$$G = \frac{F_{dyn}}{F_{static}} = \frac{16,000}{2,000} = 8.0$$

using $G = \frac{h + s}{s} = 8$ and $10 = h + s$ and $s = 70\%\ Tc$

solving $s = 1.19$ ft $h = 8.30$ ft $Tc = 1.70$ ft $= 20.40$ in.

$T =$ 20.40 in. for stroke + 0.25 in. for precrush = 20.65 in.

$W(h+s) = f_{cr}A_{cr}s$ $F_{dyn} = f_{cr}A_{cr} = \frac{W(h+s)}{s} = \frac{(2000)(8.30 + 1.19)}{1.19} = 15,950$ lbs.

$V_{at\ impact} = \sqrt{2gh} = [(2)(32.2)(8.30)]^{1/2} = 23.1$ fps

Try CRIII-1/4-5052-6.0 $f_{cr\ static} = 430$ psi $f_{cr\ dyn} = (430)(1.08) = 464$ psi
8% increase

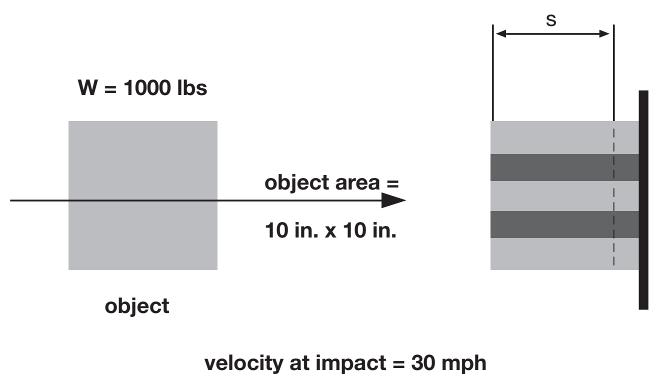
$$A = \frac{F_{dyn}}{f_{cr\ dyn}} = \frac{15,950}{464} = 34.4\ \text{in.}^2$$ use 5.86 in. x 5.86 in.

Solution:

Use CRIII-1/4-5052-6.0 honeycomb 5.86 in. L by 5.86 in. W by 20.65 in. T precrushed with a .080 in. aluminum plate bonded to the honeycomb to spread the load.

Horizontal Motion Energy Absorption Example

Horizontal Motion



Situation:

A 1000 pound object is traveling at 30 miles per hour and must be stopped.

Problem:

The object must not be subjected to more than 12 Gs.

Calculations: 30 mph x 1.467 = 44.0 fps

$G = \frac{V^2}{2gs}$ $\quad s_{req'd} = \frac{(44.0)^2}{2(32.2)(12)} = 2.50 \text{ ft} = 30.0 \text{ in.}$

$s = 70\%Tc$ $\quad T_{req'd} = \frac{30.0}{0.70}$ = 42.9 in. for stroke + 0.25 in. for precrush = 43.15 in. total

Try ACG-3/8-3.3 $\quad f_{cr\ static}$ = 120 psi $\quad f_{cr\ dyn}$ at 30 mph = (120)(1.10) = 132 psi, 10% increase

$\frac{1}{2}\frac{W}{g}V^2 = f_{cr}A_{cr}S$ $\quad \frac{1}{2}\frac{(1000)}{(32.2)}(44.0)^2 = (132)(A_{cr})(2.50)$

$A_{cr\ req'd} = 91.1 \text{ in}^2$ $\quad$ use 9.54 in. x 9.54 in.

Solution:

Use ACG-3/8-3.3 HexWeb® 9.54 in. L by 9.54 in. W by 43.15 in. T precrushed.

Honeycomb Crush Strengths

Room Temperature — Static

Type	Designation	Crush Strength (psi)	Metric (kPa)
CRIII Aluminum HexWeb®	1/8-5052-3.1	130	900
	1/8-5052-4.5	260	1800
	1/8-5052-6.1	450	3100
	1/8-5052-8.1	750	5200
	1/4-5052-1.6	40	280
	1/4-5052-2.3	75	520
	1/4-5052-3.4	150	1000
	1/4-5052-4.3	230	1600
	1/4-5052-5.2	190	1300
	1/4-5052-6.0	430	3000
	1/4-5052-7.9	725	5000
	3/8-5052-1.0	25	170
	3/8-5052-1.6	40	280
	3/8-5052-2.3	75	520
	3/8-5052-3.0	120	830
	3/8-5052-3.7	180	1200
	3/8-5052-4.2	220	1500
	3/8-5052-5.4	360	2500
	3/8-5052-6.5	505	3500
	ACG-1-1.3	25	170
	ACG-3/4-1.8	45	310
	ACG-1/2-2.3	60	410
	ACG-3/8-3.3	120	830
	ACG-1/4-4.8	245	1700
	ALC-1/8-5052-12.0	1450	10000
	ALC-1/8-5052-14.5	2200	14500
	ALC-1/8-5052-22.1	4100	28000
	ALC-1/8-5052-38.0	5650	39000
	ALC-3/16-5052-15.7	2100	14500
	ALC-3/16-5052-25.0	2900	20000
	CROSS-CORE®	SEE DATA SHEET	SEE DATA SHEET
	TUBE-CORE®	SEE DATA SHEET	SEE DATA SHEET

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Australia
Suite 2, 86 Grimshaw Street
Greensborough, Victoria 3088
Tel: **61** 3 9432 7100
Fax: **61** 3 9432 7200

China
Room B707, Yin Hai Bldg.
250 Cao Xi Rd
Shanghai 200233
Tel: **86** 21 6483 6741/2
Fax: **86** 21 6483 6744

Japan - Joint Venture
DIC - Hexcel Limited
7F Nissei Bldg.
6-2-8 Sotokanda
Chiyoda-ku, Tokyo 101-0021
Tel: **81** (0)3 5812 3361
Fax: **81** (0)3 3837 7522

USA
900 Main Street South
Building 1, Suite 104
Southbury, CT 06488
Tel: **1** 203 267 1414
Fax: **1** 203 267 1561

Austria
Industriestrasse 1
A-4061, Pasching
Tel: **43** (0)7229 7720
Fax: **43** (0)7229 772299

France
Z1 La Plaine, B.P.27 Dagneux
01121 Montluel CEDEX
Tel: **33** (0)4 72 25 26 27
Fax: **33** (0)4 72 25 27 30

Spain
Bruselas, 10 - 16
Polig. Ind. "Ciudad de Parla"
28980 Parla, Madrid
Tel: **34** 91 664 4900
Fax: **34** 91 698 4914

USA
2350 Airport Freeway, Suite 550
Bedford, TX 76022-6027
Tel: **1** 817 315 3939
Fax: **1** 817 571 8629

Belgium
Rue Trois Bourdons, 54
B-4840 Welkenraedt
Tel: **32** 87 307 411
Fax: **32** 87 882 895

Germany
Postfach 1560
21655 Stade
Tel: **49** 4141 7879-00
Fax: **49** 4141 7879-01

United Kingdom
Duxford, Cambridge
CB2 4QD
Tel: **44** (0)1223 833141
Fax: **44** (0)1223 838808

USA
PO Box 18748
Salt Lake City, UT 84118-0748
Tel: **1** 800 987 0658
Fax: **1** 801 508 8103

Brazil
Av. J. Guilhermino, 474/72
S.J.Campos, SP 12210-130
Tel: **55** 12 3941 2242
Fax: **55** 12 3923 1186

Italy
Via San Cristoforo, 44
21047 Saronno (VA)
Tel: **39** 02 96709082
Fax: **39** 02 9600809

USA
11711 Dublin Blvd.
Dublin, CA 94568-2832
Tel: **1** 925 551 4900
Fax: **1** 925 828 9202

USA
16310 NE 80th Street, Suite 102
Redmond, WA 98052
Tel: **1** 425 558 4400
Fax: **1** 425 861 5847

March 2005
(Formerly TSB122)