Lightweight Cellular Metals with High Structural Efficiency

NATO Advanced Research Workshop, "Metallic Materials with High Structural Efficiency"

September 8-12, 2003   Kiyv, Ukraine

Capt. Wynn S. Sanders, Sc.D.
Project Leader, Nano and Amorphous Materials Research
Materials and Manufacturing Directorate
Air Force Research Laboratory

MIT Cellular Solids Research Group

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **18 MAR 2004**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**
4. TITLE AND SUBTITLE **Lightweight Cellular Metals with High Structural Efficiency**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Nano and Amorphous Materials Research Materials and Manufacturing Directorate Air Force Research Laboratory**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM001672., The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**UU**	**26**	

Standard Form 298 (Rev. 8-98)
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Outline

Introduction to Cellular Solids

Production of Cellular Metals

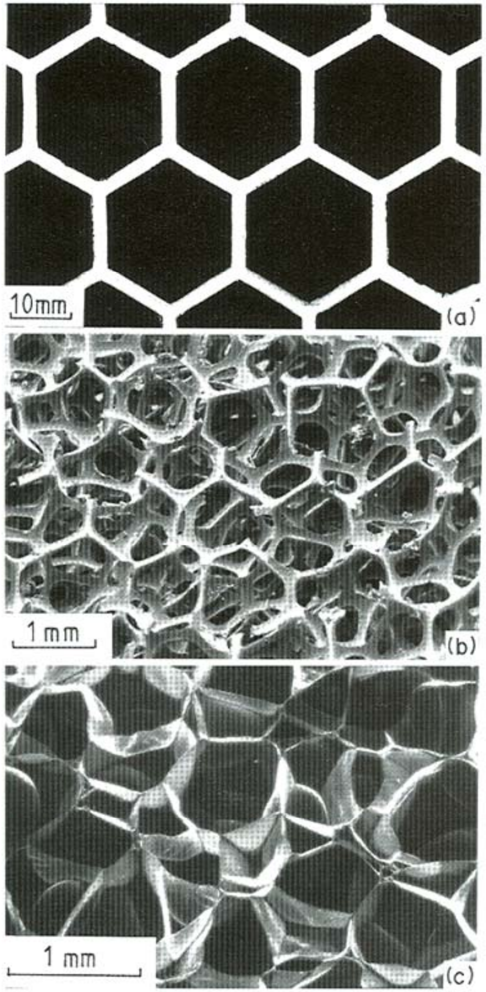
Behavior of Cellular Metals

Applications of Cellular Metals

Summary

What is a cellular solid?

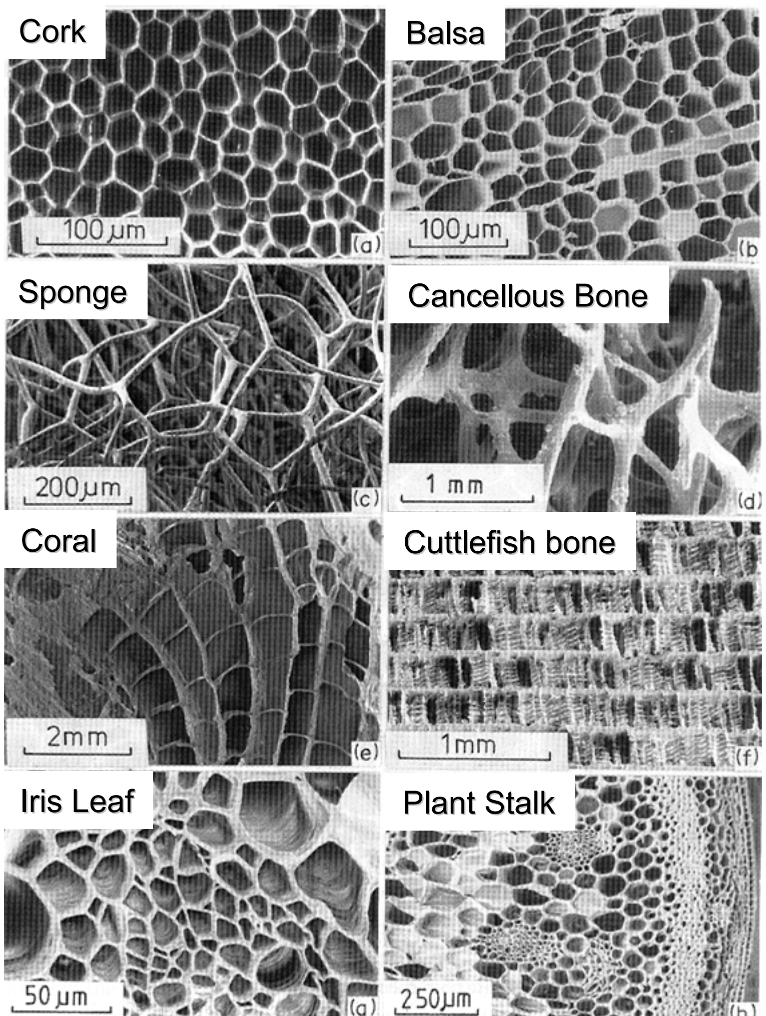
- Interconnected network of solid struts or plates that form edges and faces of cell
- Relative Density
  - Density of foam divided by density of solid
- Can be produced from wide variety of materials
  - Polymers, ceramics, metals, food



Gibson & Ashby, 1997

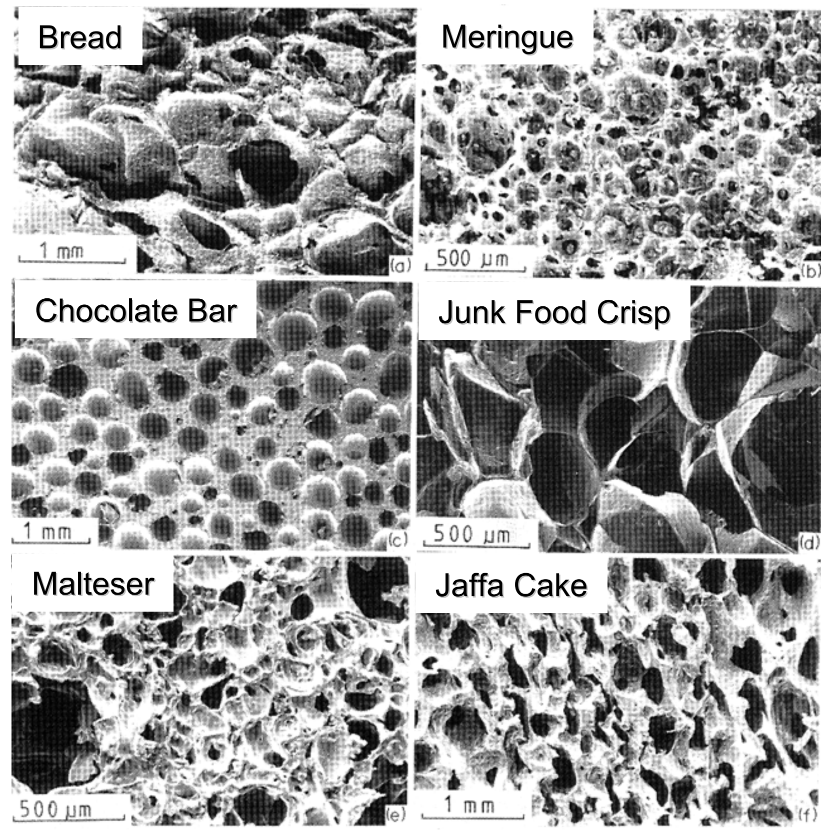
What is a cellular solid?

Natural Cellular Materials



Gibson & Ashby, 1997

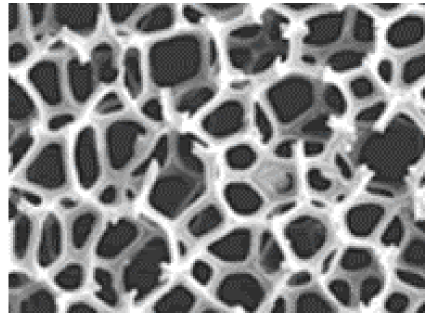
Food Foams



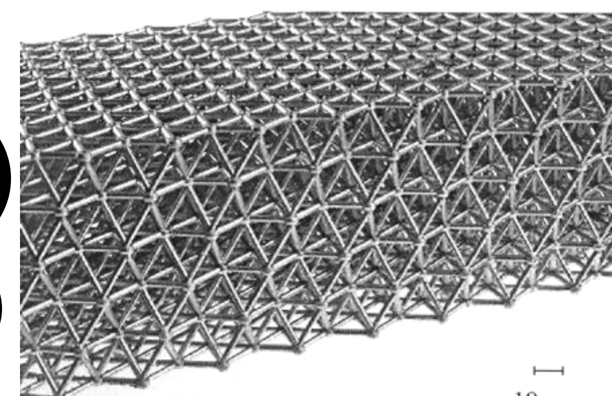
Gibson & Ashby, 1997

Topology of Cellular Metals

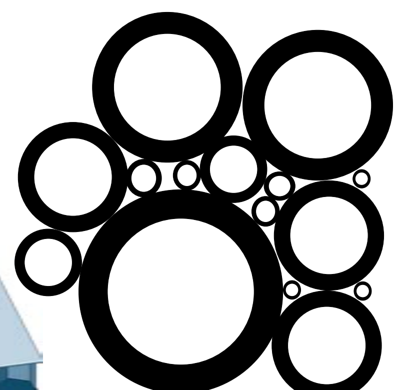
- **Open-cell foam**
- **Closed-cell foam**
- **Hollow-sphere foam**
- **Periodic/optimized truss structures**
  - **Octet, pyramidal, tetrahedral, kagomé truss**
- **Hashin-Shtrikman Material**
- **Honeycomb**



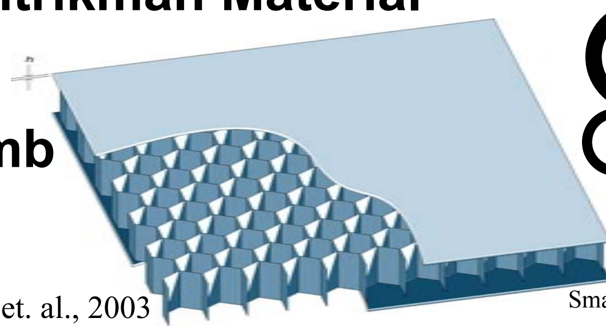
Inco Limited



Deshpande et. al., 2000



Smaller spheres not drawn for convenience



Wadley et. al., 2003

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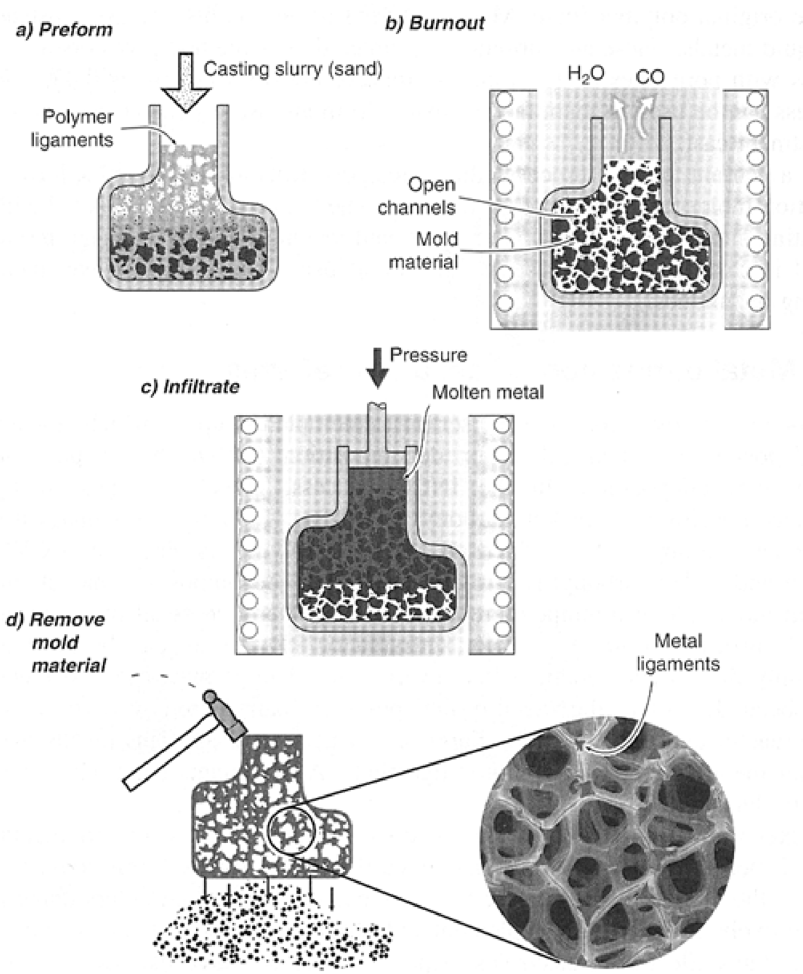
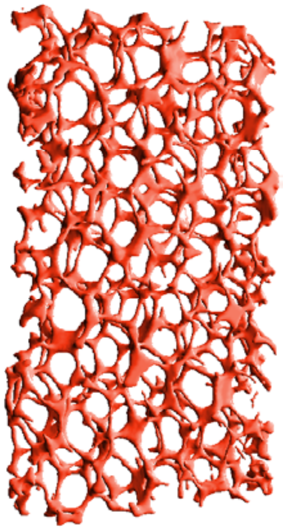
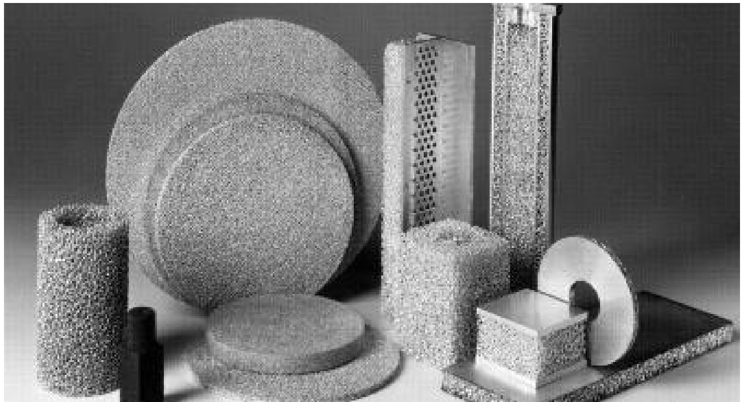
Open-Cell Foams:



Ashby et. al., 2000



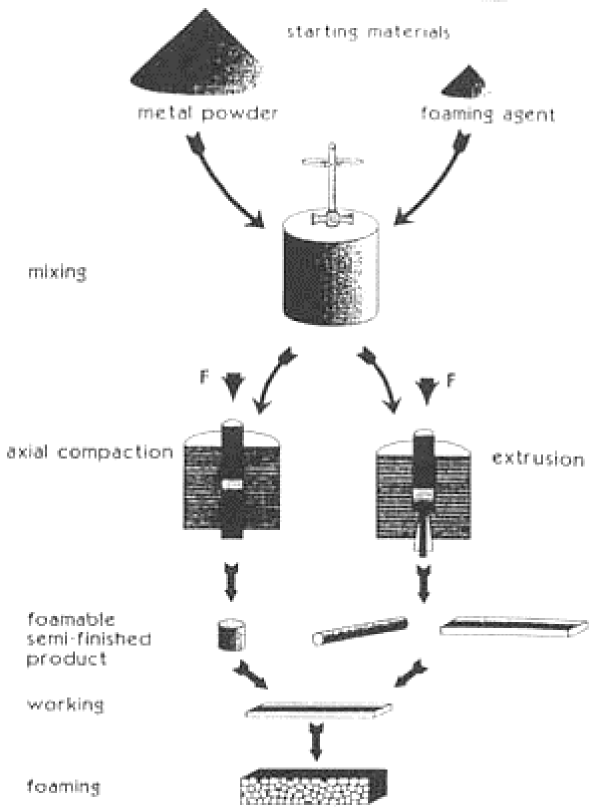


ERG Aerospace, Inc.

Production of Cellular Metals

Closed-Cell Foams:

Fraunhofer Foam Production



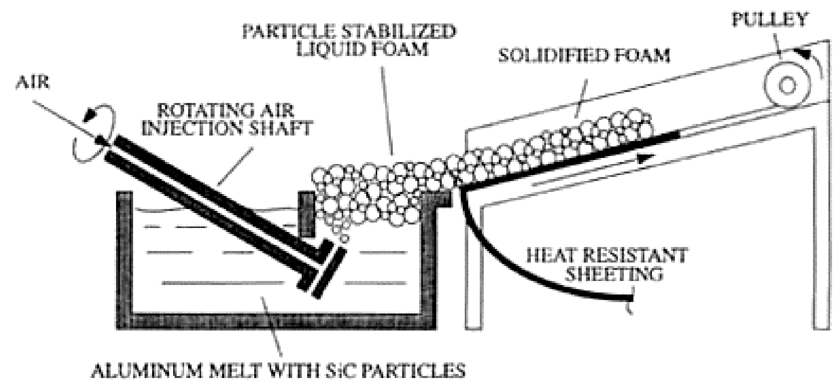
TiH_2 decomposes at 400°C

T_M = 660°C for aluminum

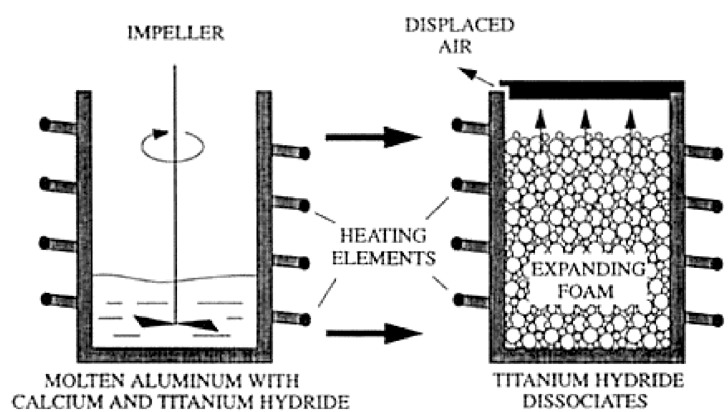
Al, Zn, Pb, Ti foams

From Banhart et al. (1996) Mat. Sci. Eng. A205, 221-228

Alcan Al/SiC Foam Production



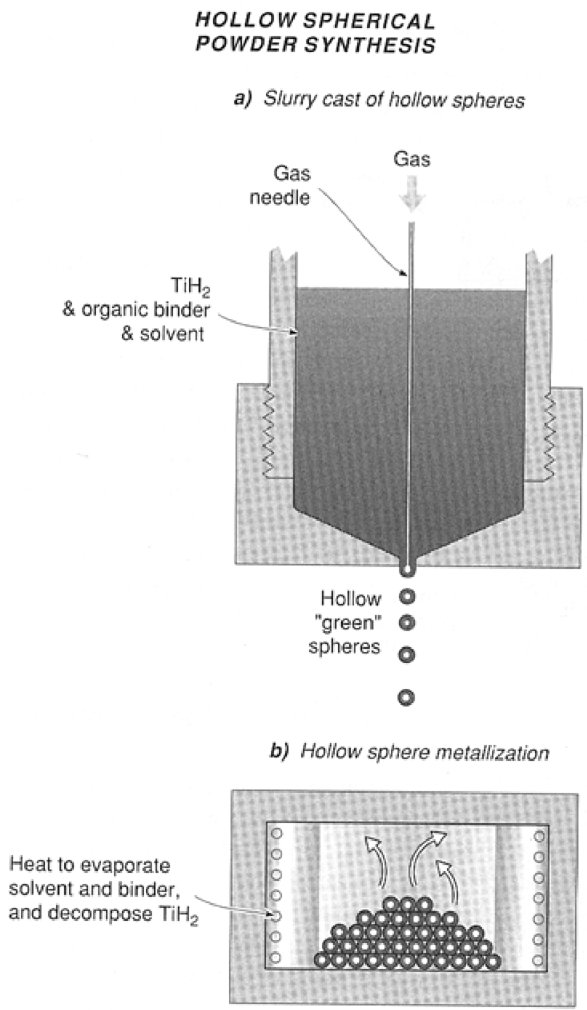
ALPORAS Foam Production



Simone and Gibson, 1997

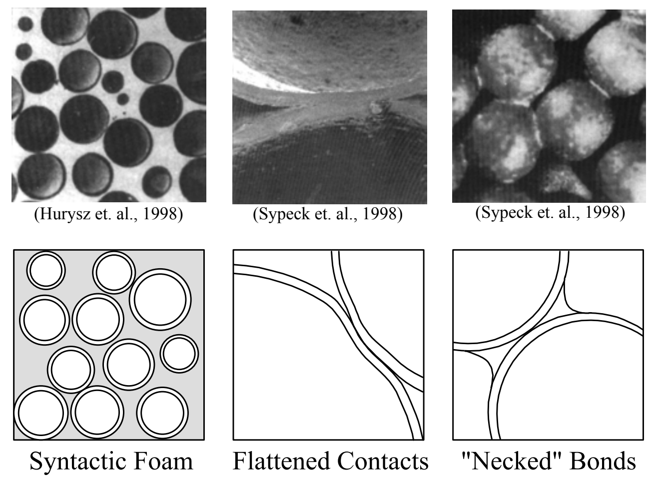
Production of Cellular Metals

Hollow-Sphere Foams:



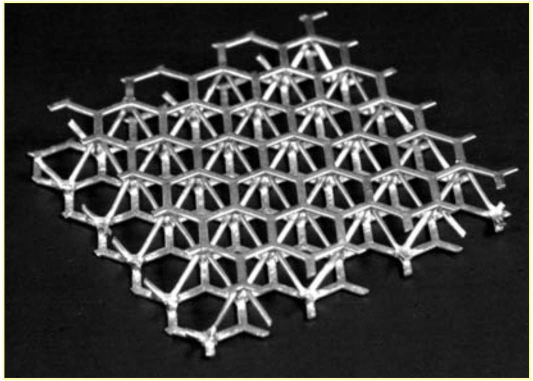
Ashby et. al., 2000

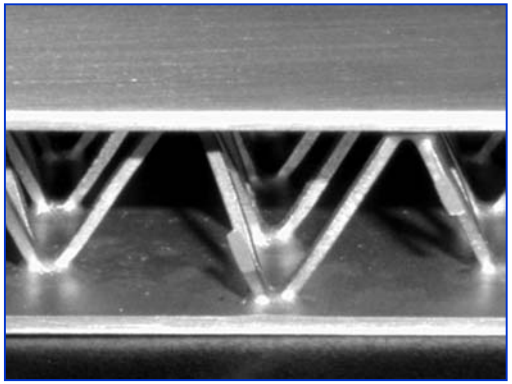
- **Also produced via fluidized bed coating (ATECA) and mechanical forming/joining (Kaydon ITI)**
- **Joined using second phase (epoxy, solder) or diffusion bonding**

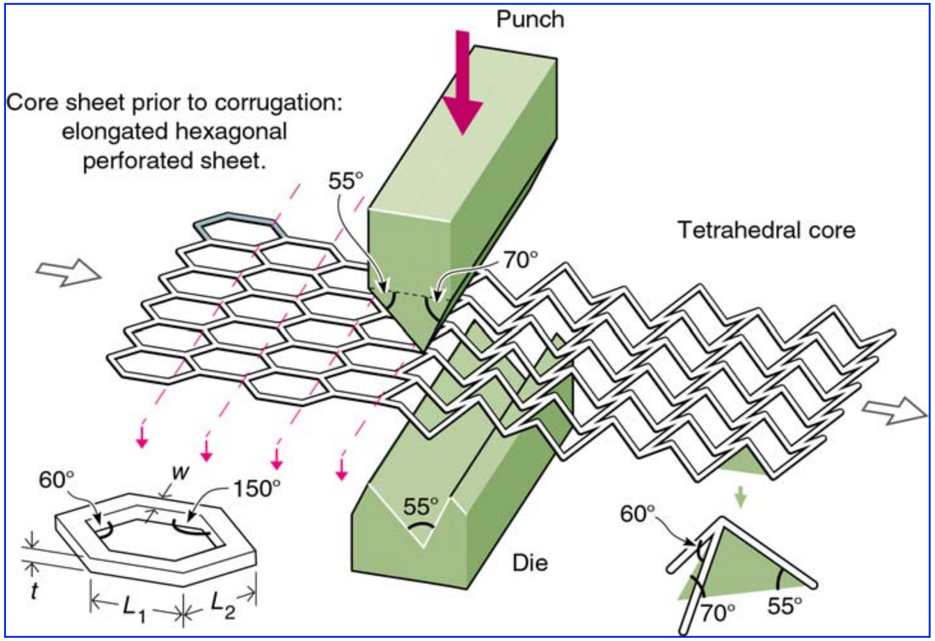


Production of Cellular Metals

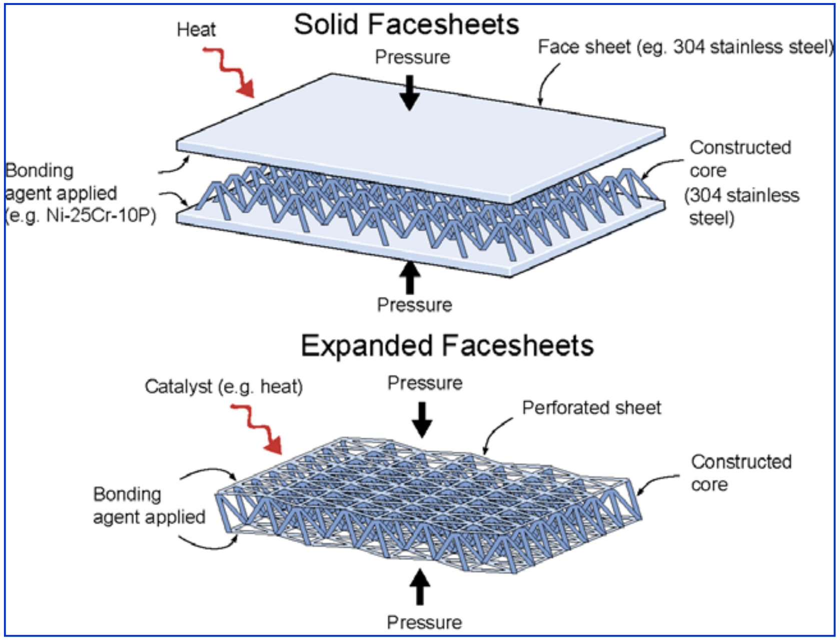
Truss Structures:







Wadley et. al., 2003

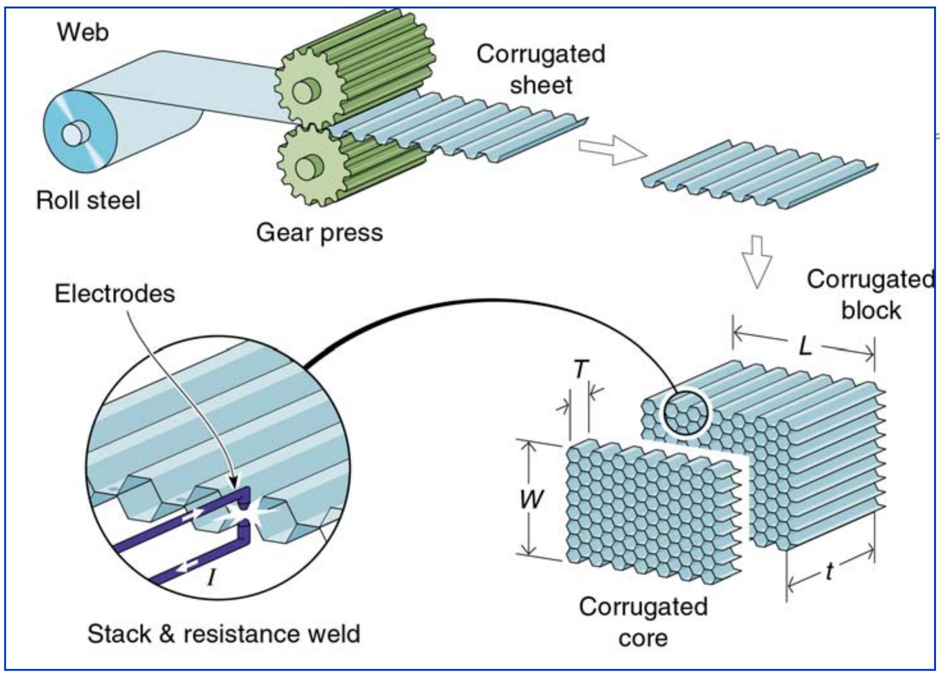


Wadley et. al., 2003

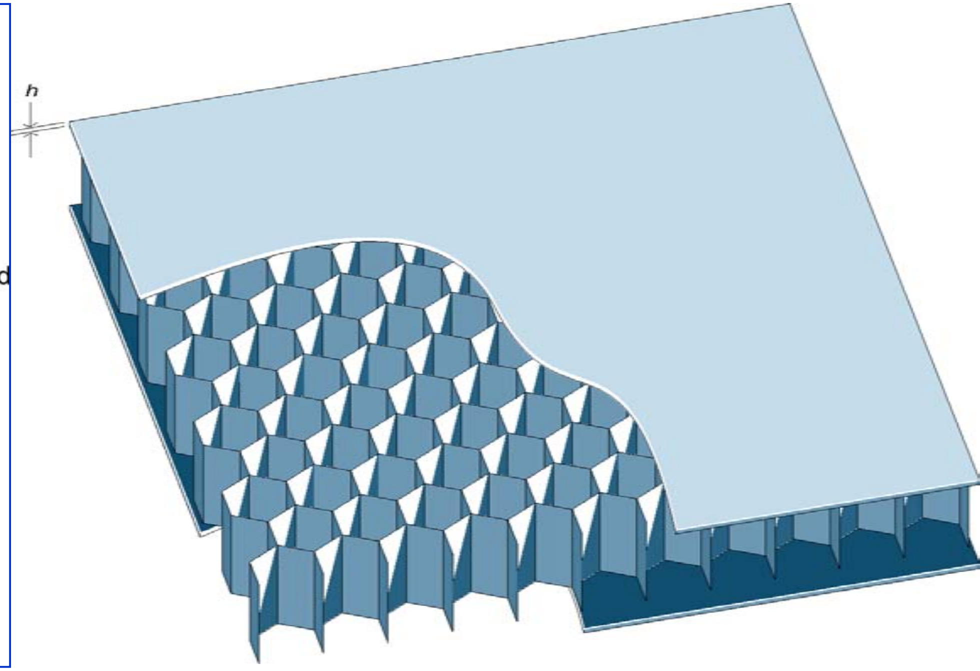
Production of Cellular Metals

Honeycomb Structures:

• Includes hexagonal, square, and triangular honeycomb



Wadley et. al., 2003



Wadley et. al., 2003

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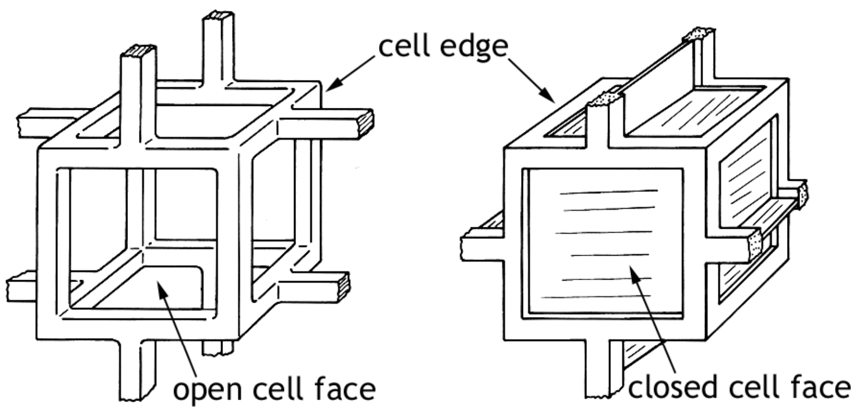
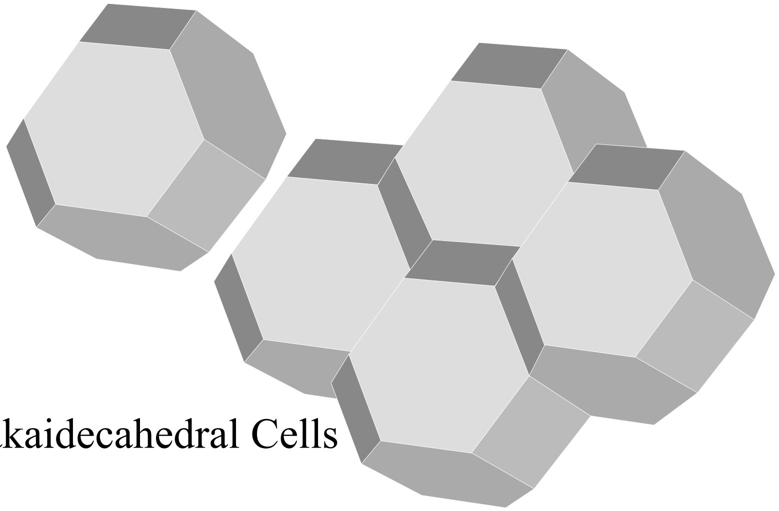
Stochastic Foams: Models



[Gibson and Ashby, 1997]

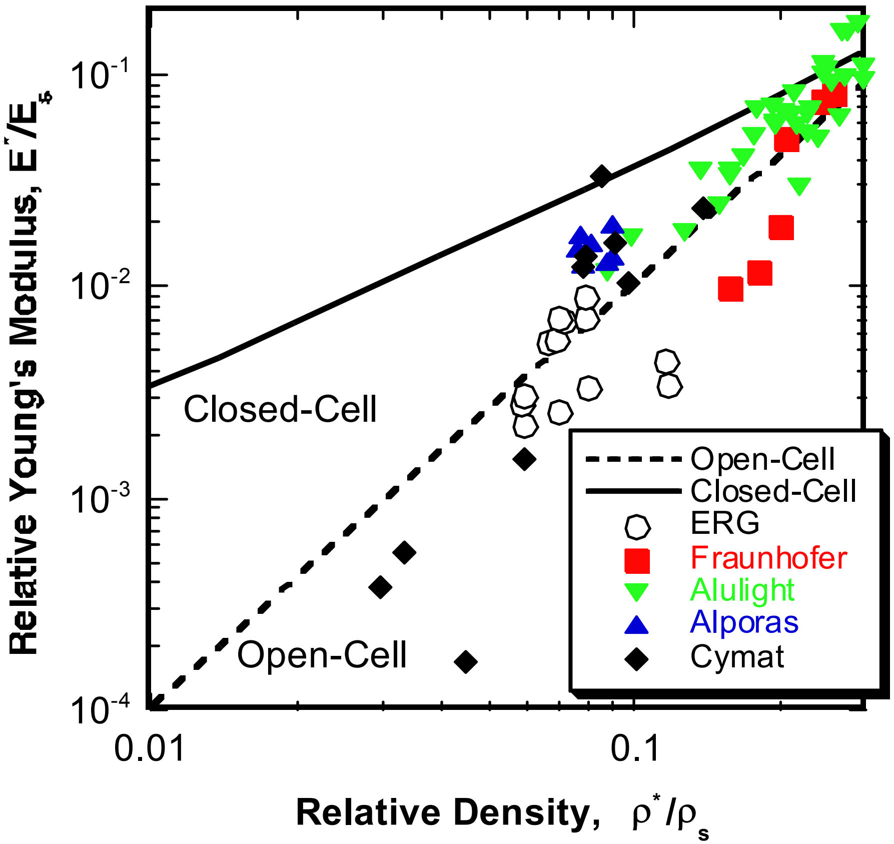


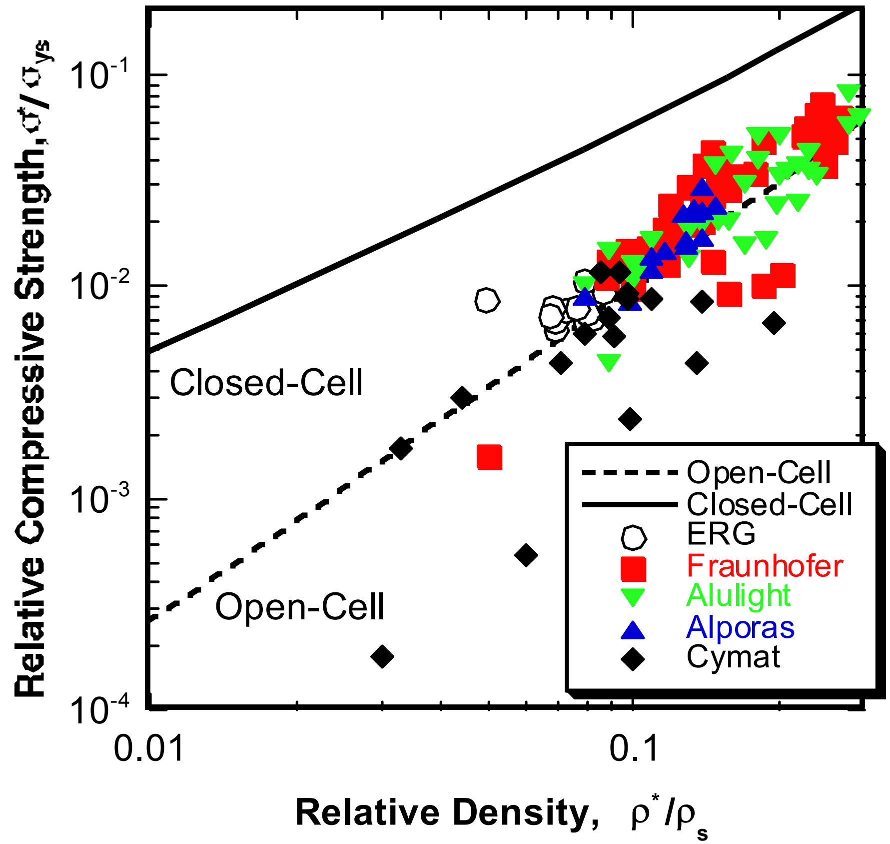
Tetrakaidecahedral Cells

[Simone and Gibson, 1998]

Behavior of Cellular Metals

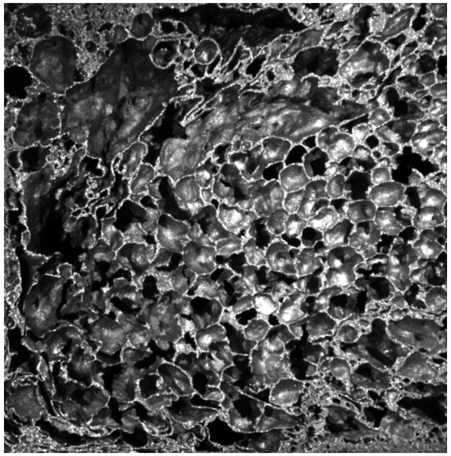
Stochastic Foams: Modulus and Strength

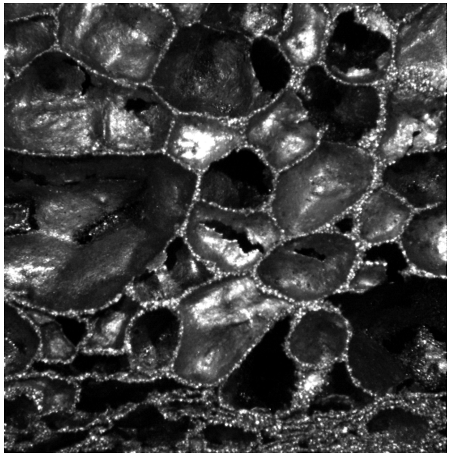


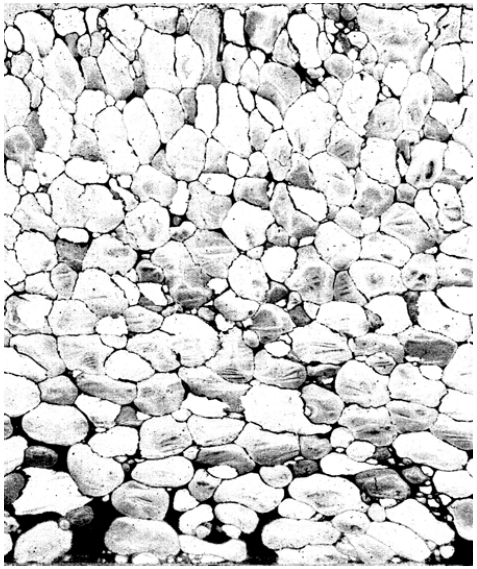


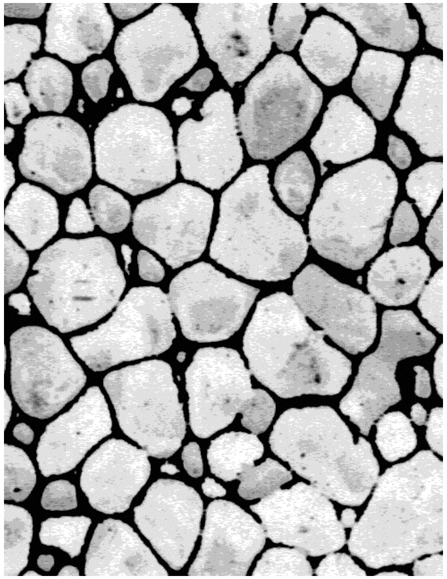
Behavior of Cellular Metals

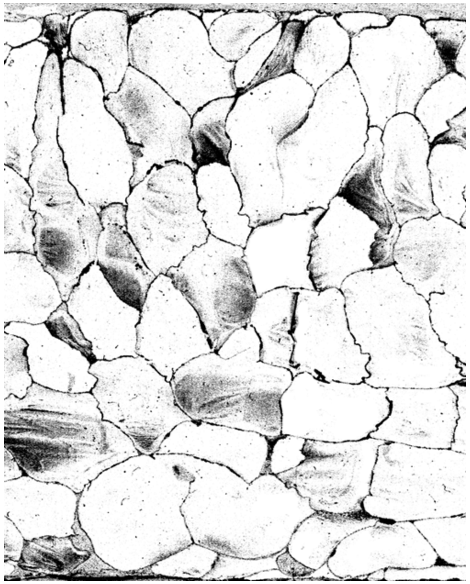
Stochastic Foams: Defects


Non-homogenous cells


Torn/fractured cell walls

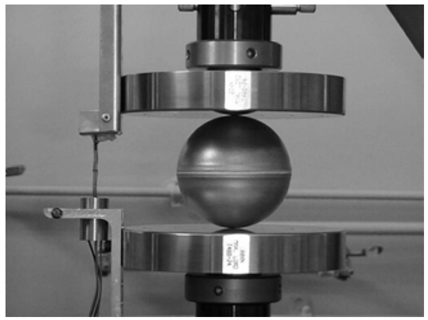

Liquid Drainage

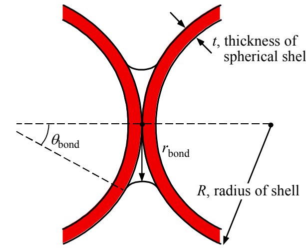

Curvature

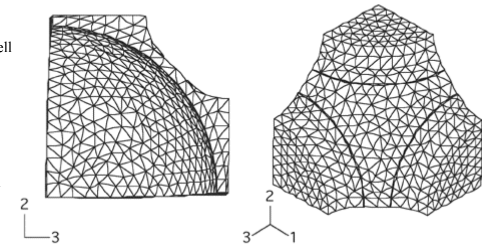

Corrugation

Behavior of Cellular Metals

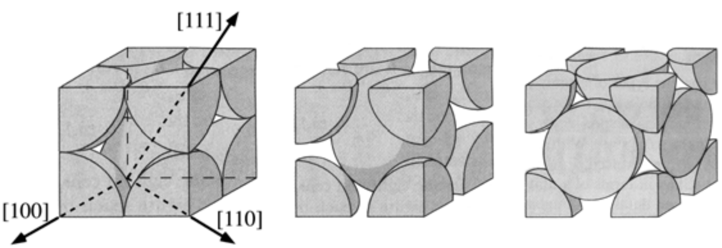
Hollow-Sphere Foams: Analytical, experimental, and FEM analysis

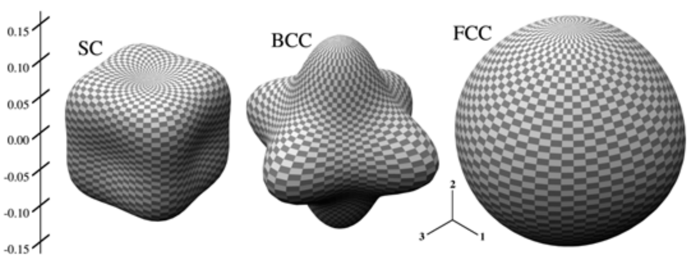




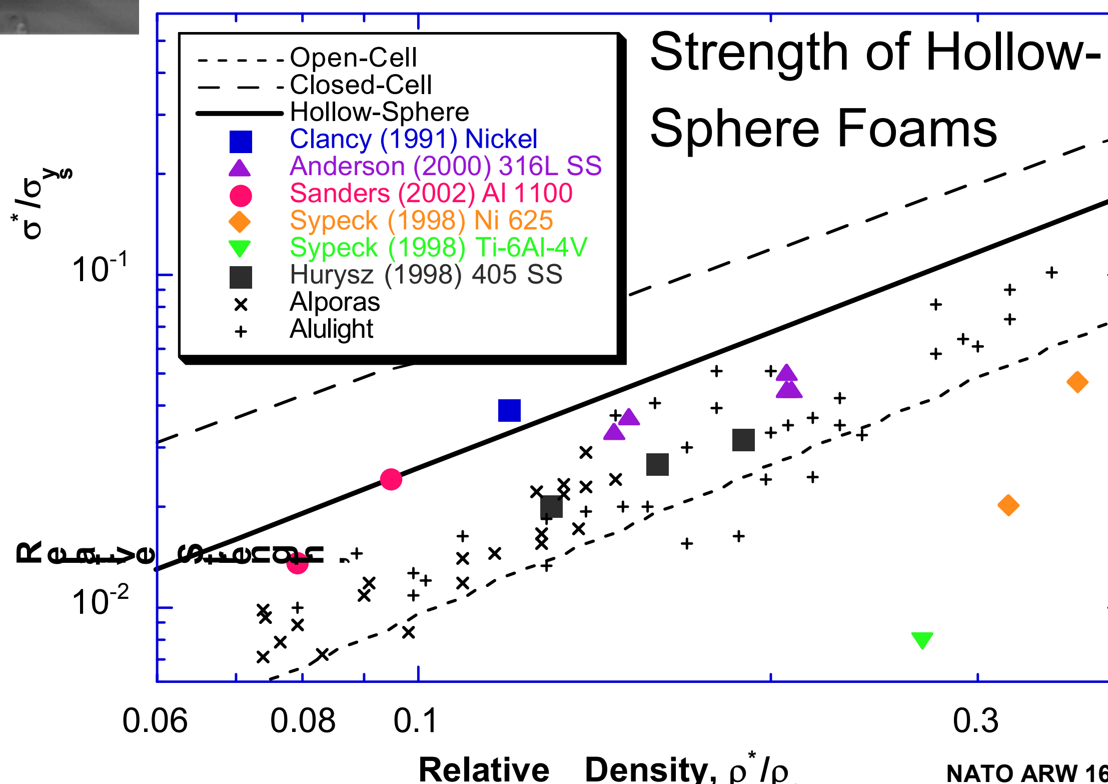


Kinkead et. al., 1994



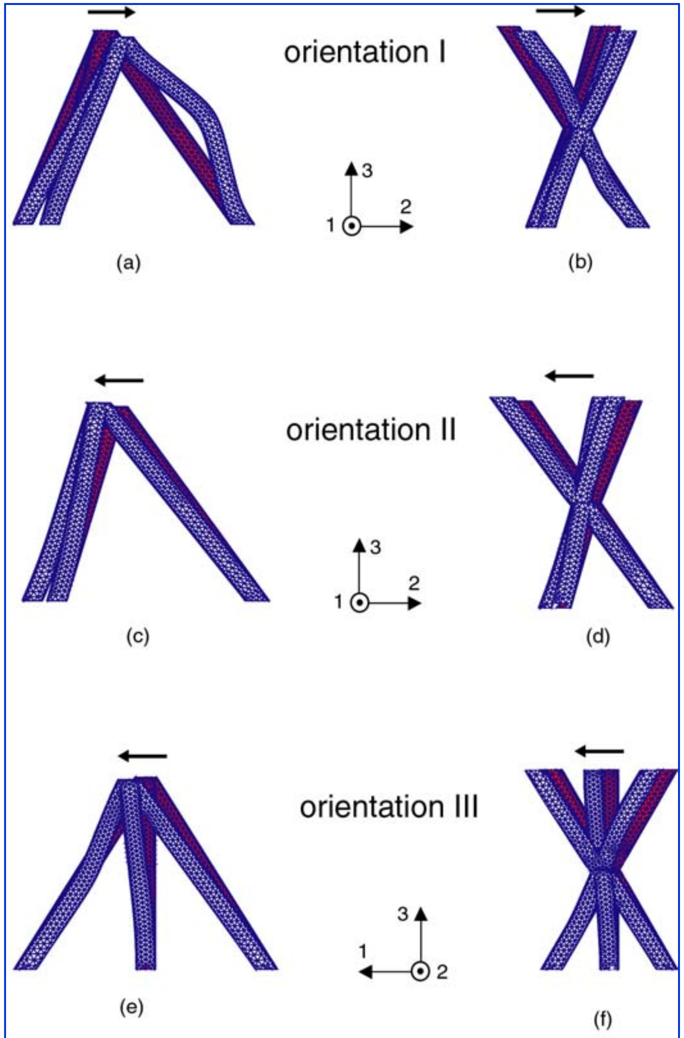


Elastic Representation Surfaces ($t/R = 0.1$, $\theta = 30°$)

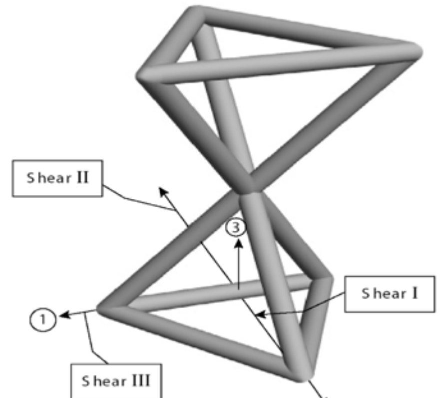


Behavior of Cellular Metals

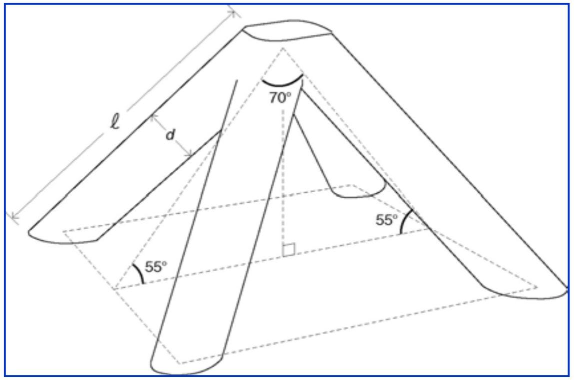
Truss Structures:



Wadley et. al., 2003



Wadley et. al., 2003



Wadley et. al., 2003

Topology	Elastic Modulus	Shear Modulus	Compressive Strength	Min Shear Strength	Max Shear Strength
	(E_{33}/E_s)	(G_{13}/E_s)	(σ_{33}/σ_y)	(τ/σ_y)	(τ/σ_y)
Hexagonal Honeycomb	$1.00(\rho/\rho_s)$	$0.14(\rho/\rho_s)$	$3.22(\rho/\rho_s)^{5/3**}$	-	$1.61(\rho/\rho_s)^{5/3}$
Diamond Textile	$0.25(\rho/\rho_s)$	-	$0.78(\rho/\rho_s)^*$	-	$0.5(\rho/\rho_s)^*$
Square Textile	$0.50(\rho/\rho_s)$	-	$0.56(\rho/\rho_s)^*$	-	$0.08(\rho/\rho_s)^*$
Diamond Hollow Tube	$0.25(\rho/\rho_s)$	-	$0.47(\rho/\rho_s)^*$	-	-
Square Hollow Tube	$0.50(\rho/\rho_s)$	-	$0.90(\rho/\rho_s)^*$	-	-
Tetrahedral	$0.44(\rho/\rho_s)$	$0.11(\rho/\rho_s)$	$0.67(\rho/\rho_s)$	$0.24(\rho/\rho_s)$	$0.27(\rho/\rho_s)$
Pyramidal	$0.25(\rho/\rho_s)$	$0.13(\rho/\rho_s)$	$0.50(\rho/\rho_s)$	$0.25(\rho/\rho_s)$	$0.35(\rho/\rho_s)$
3D Kagome	$0.44(\rho/\rho_s)$	-	$0.73(\rho/\rho_s)$	$0.21(\rho/\rho_s)$	$0.21(\rho/\rho_s)$

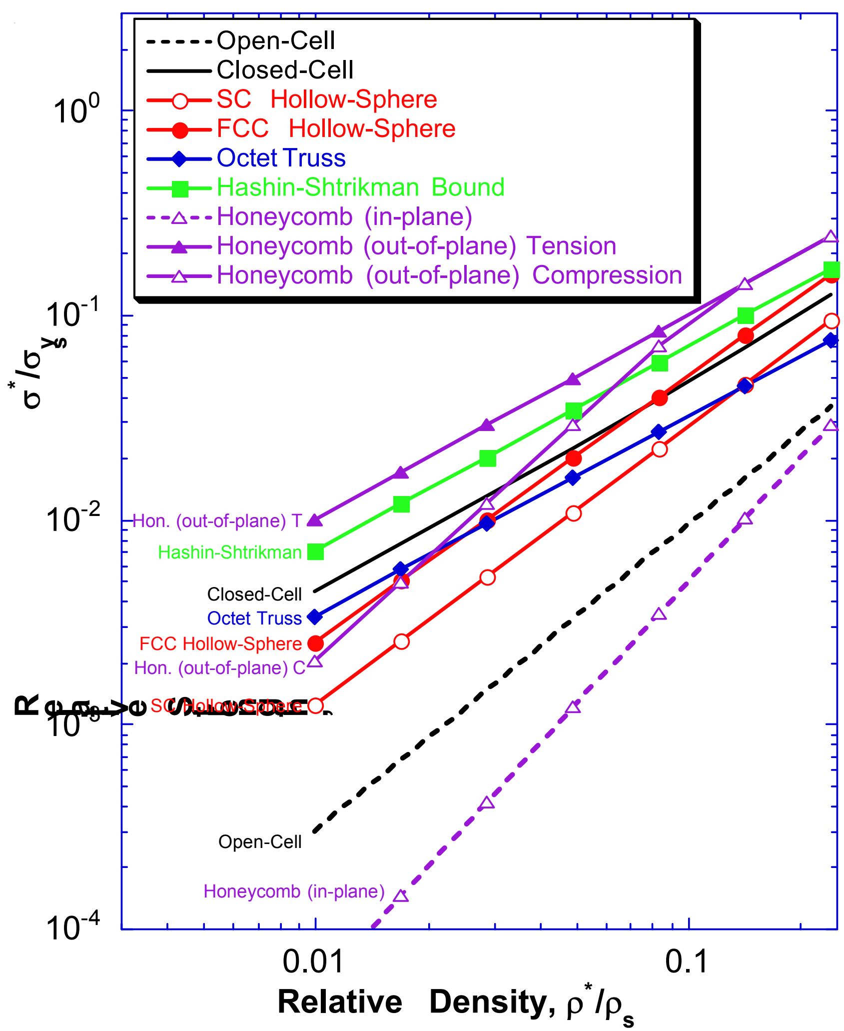
(*Experimental Results) (** Plateau Stress)

Wadley et. al., 2003

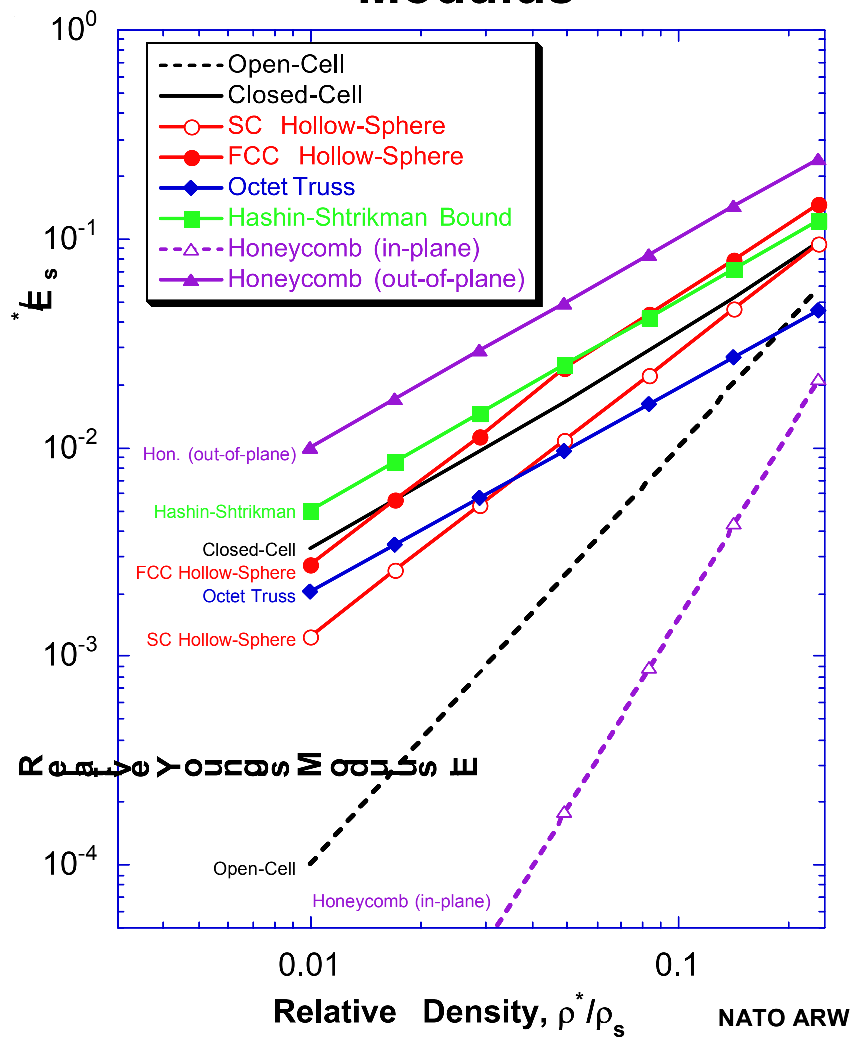
Behavior of Cellular Metals

A Comparison:

Strength

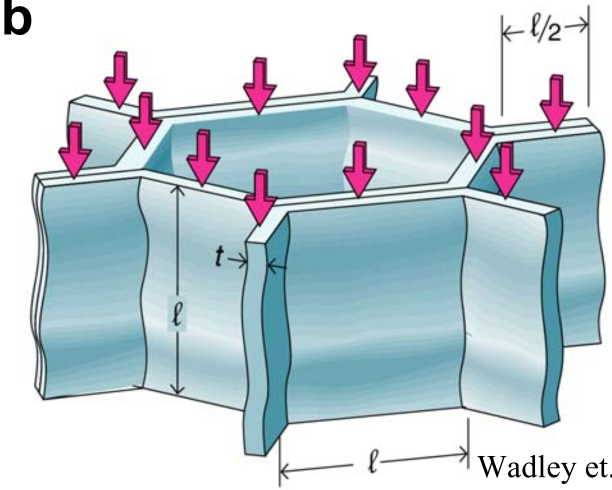


Modulus

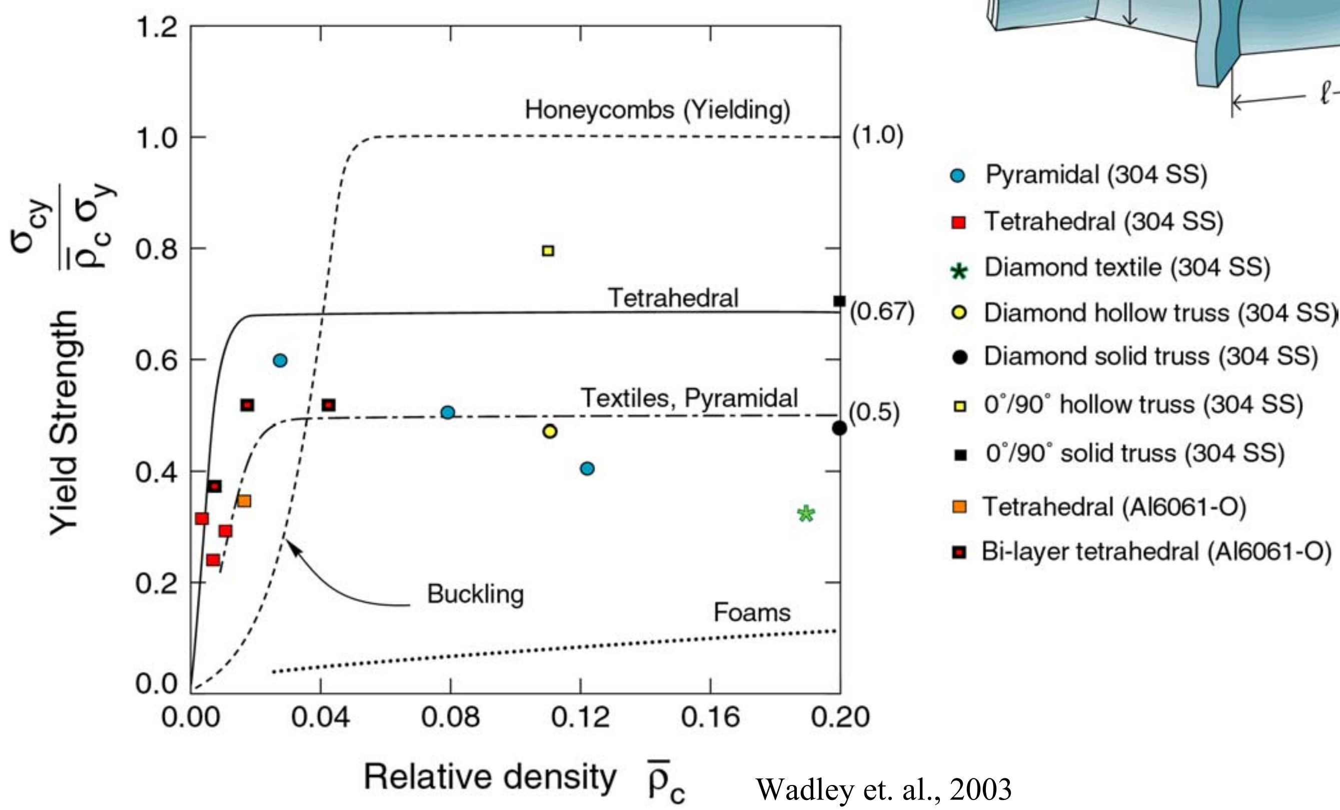


Behavior of Cellular Metals

A Comparison: Drawback of honeycomb



Wadley et. al., 2003



Wadley et. al., 2003

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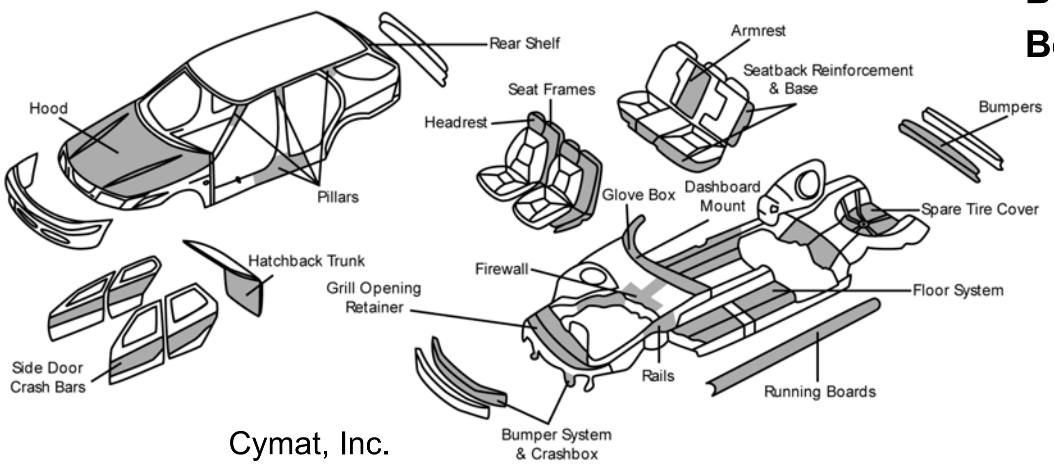
Applications of Cellular Metals

Cellular metals posses a unique set of properties

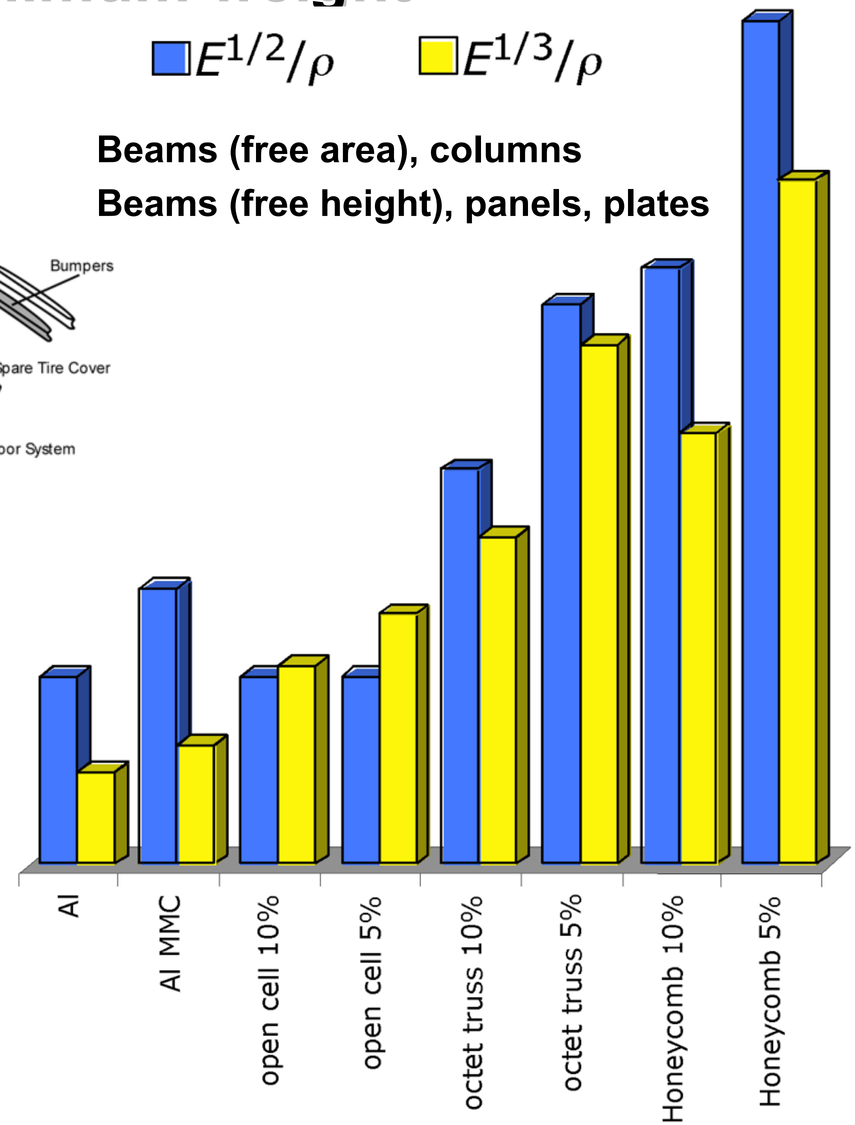
Lightweight Structures	Excellent stiffness to weight ratio when loaded in bending: attractive values of $E^{1/3}/\rho$, $E^{1/2}/\rho$, and $\sigma_y^{1/3}/\rho$ for panels, plates, beams, and columns.
Sandwich Cores	Low density with good shear and fracture strength.
Mechanical Damping	Damping capacity of metal foams is up to 10X larger than that of solid metals.
Vibration Control	Cellular metal panels have higher natural vibration frequencies that solid sheet of the same mass per unit area.
Acoustic Absorption	Reticulated structures (open porosity) have sound absorbing capacity.
Thermal Management	Open-cell structures posses large surface area and high cell wall/strut conduction for exceptional heat transfer ability
Energy Absorption	Cellular metals have exceptional ability to absorb energy at almost constant pressure: crash protection, blast protection

Applications of Cellular Metals

Stiffness limited design at minimum weight

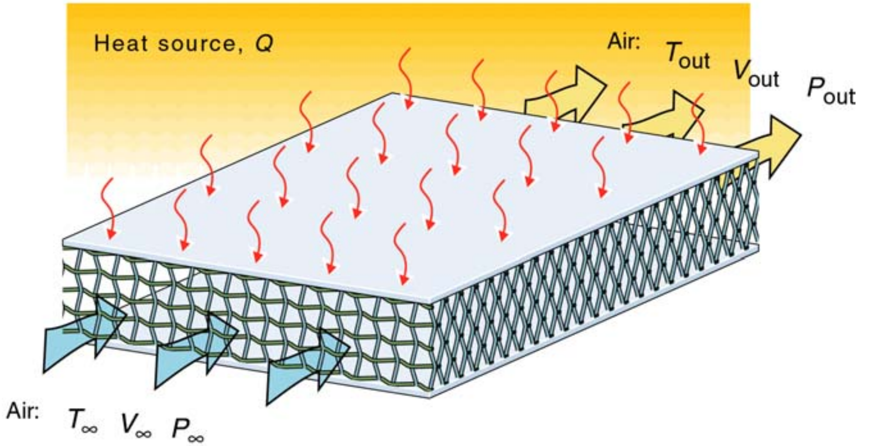


Cymat, Inc.



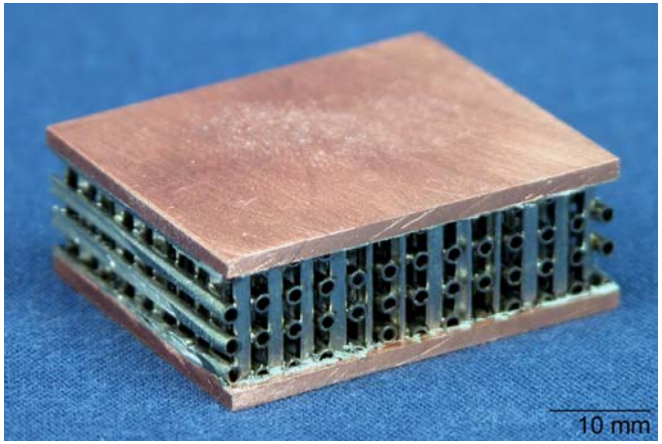
Applications of Cellular Metals

Heat Transfer Applications



Ashby et. al., 2000

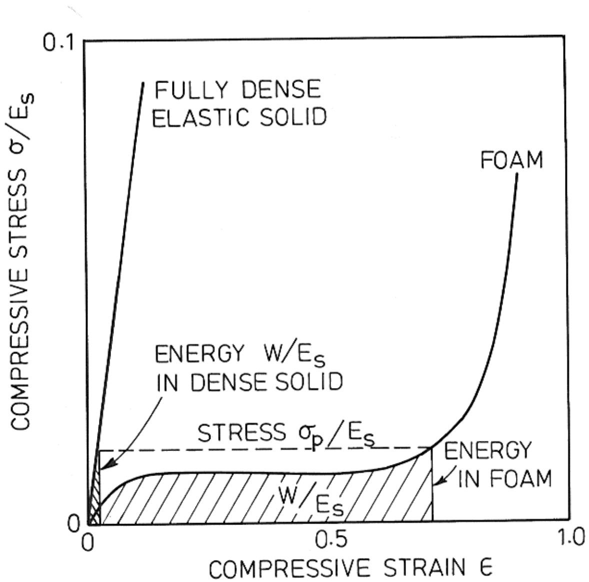
ERG Aerospace



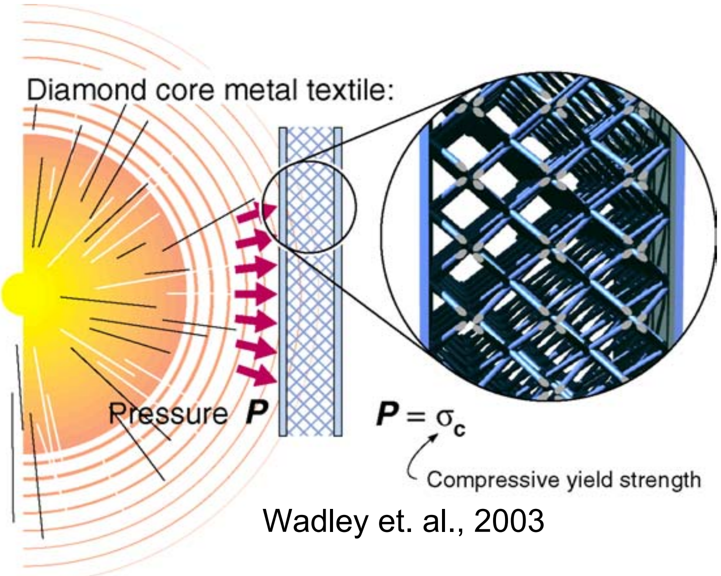
Wadley et. al., 2003

Applications of Cellular Metals

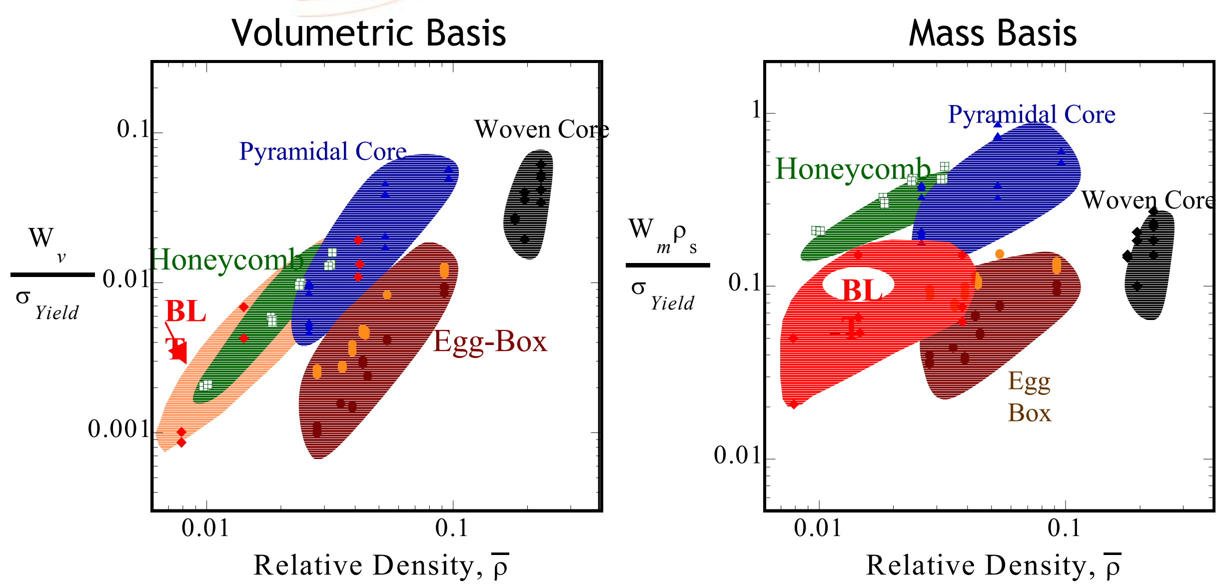
Energy Absorption



Gibson and Ashby, 2000



Wadley et. al., 2003



Fleck et. al., 2002

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- A range of cellular metals presented as a structural concept, independent of material properties
  - Stochastic foams, hollow-sphere foams, periodic trusses
- Cellular metals posses high structural efficiency that provides added benefits over a fully dense material
- Lightweight structure used in application will depend on manufacturability and cost of each process
- Range of properties of cellular metals allows multifunctional use beyond simple structural concepts
  - Allows for further weight savings

Nature has a magnificent way of achieving great structural feats using only limited resources!