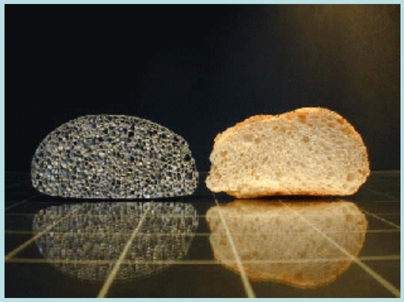
Solid Cellular Materials



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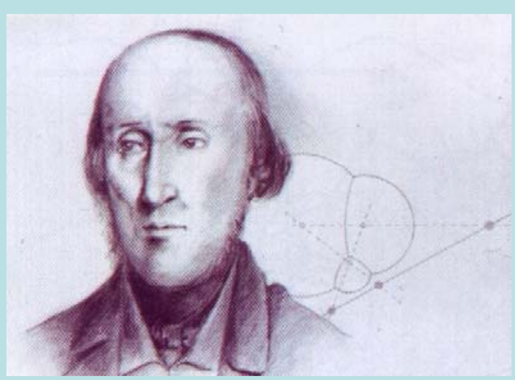
Solid Foams

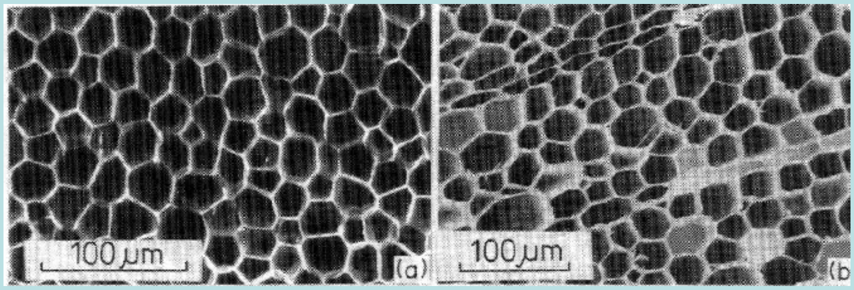
Define "foam"?

First make a foam which Plateau would recognise, then freeze it.

To make an open cell foam, remove the films.

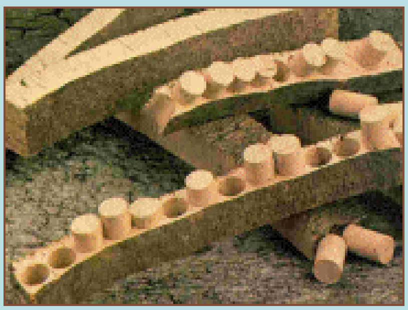


Natural solid foams



Gibson & Ashby

Cork Balsa



Fortes, Rosa, Pereira, *A cortiça* (2004)

Bones

Closed cell at high density, open cell at low density
Need bio-compatible engineered solid foams

Cellular Solids

Important properties of bulk constituent:

•Young's modulus E

•Specific Heat C

•Thermal conductivity K

•Thermal expansion α

•Polymers: low K, high C, high α

•Metals: high K, low C, intermediate α

•Ceramics & glasses: intermediate K, intermediate C, low α

source: Gibson & Ashby

Mechanical properties

Important properties of foam:

•Young's modulus E^*

•Shear modulus G^*

•Relative density ρ^*/ρ

•Open cell:

$E^*/E,\ G^*/E \sim (\rho^*/\rho)^2$ *(bending of PBs)*

•Closed cell:

$E^*/E,\ G^*/E \sim \varphi^2(\rho^*/\rho)^2 + (1-\varphi)\rho^*/\rho$ *(bending of PBs, film stretching, gas pressure)*

where φ is the fraction of the solid contained in the PBs.

source: Gibson & Ashby

Cellular Metals

• *cellular metals*: metallic body with any kind of gaseous voids dispersed within it

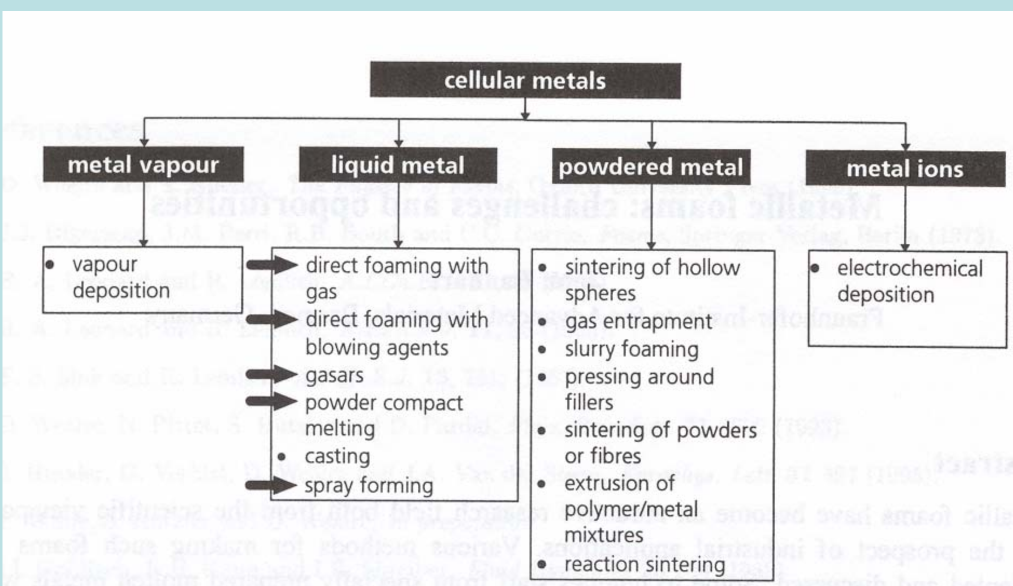
• *porous metals*: more general, but pores usually spherical and isolated

• *metal foams*: cellular metals formed from a liquid state (closed cell)

•*metal sponges*: both phases continuous (open cell)

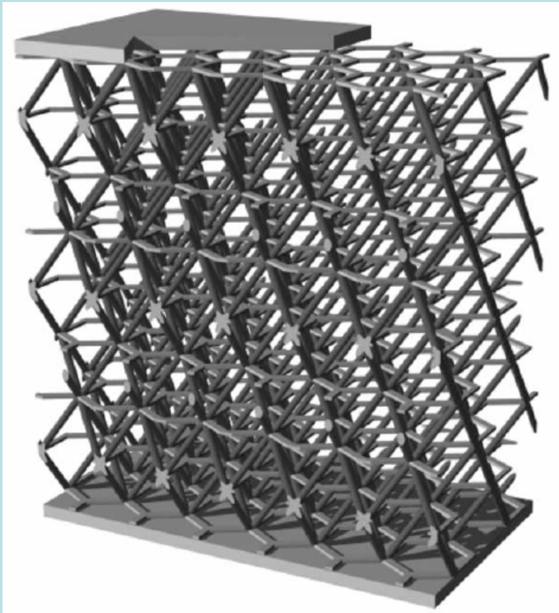
source: Banhart, Proc. Eufoam 2000

Production Routes



source: Banhart, Proc. Eufoam 2000

Cellular Metal Structures



Strong at low relative density but <u>anisotropic</u>

Wadley *et al*. Composites Science and Technology 63 (2003) 2331.

Metal foams

Advantages:

•Lightweight and strong - strength to weight ratio (stiffness) similar to steel, especially in sandwiches or as a filler in tubes

•Energy absorption and vibration suppression

•Acoustic and thermal insulation (firewall)

Applications as heat exchangers and particularly in automotive industry:
structural reinforcement and energy absorption in door panels, front hoods, bumpers, roof panels and body frame elements (www.cymat.com).
Low weight implies increased fuel efficiency, less metal means cheaper, and they are recyclable

Metal foam production

•Direct foaming by gas injection (e.g. Cymat)

•Foaming liquid metals with blowing agents (Shinko Wire Co., Alporas)

•Eutectic solidification (Gasar: melt metal in H_2 atmosphere at high pressure)

•Foaming of powder compacts

Supplier	Trade Name
The Fraunhofer Institute, Bremen, Germany	"IFAM" (aluminum foam)
Alulight International, Austria	"Alulight" (aluminum foam)
INCO Special Products, Canada	"INCO" (nickel foam)
Cymat Corporation, Canada	"Cymat" (aluminum foam)
Shinko Wireco, Japan	"Alporas" (aluminum foam)
ERG, Oakland, CA, USA	"Duocel" (aluminum foam)
DMI, Ukraine	"Gasar" (copper foam)

(source: grantadesign.com
see also www.metalfoam.net)

Metal foams

Duarte & Banhart, Acta Mater.

First make a foam which Plateau would recognise, then freeze it.

Issues:
liquid drainage
film stability

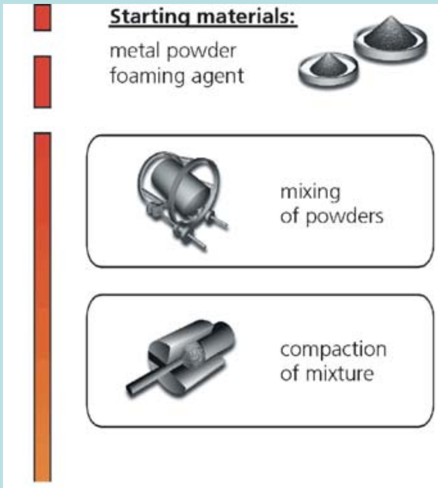
Increase viscosity, e.g by adding solid particles to the melt, which also appear to *increase* stability.

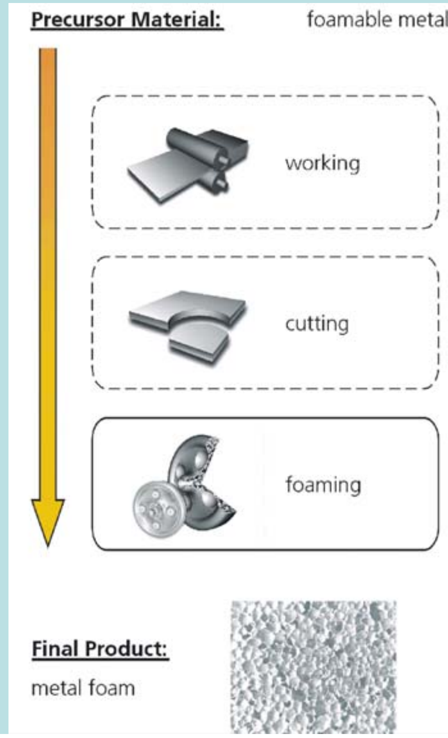
Oxide layer.

Microgravity!

Duarte & Banhart, Acta Mater.

Powder metallurgical route





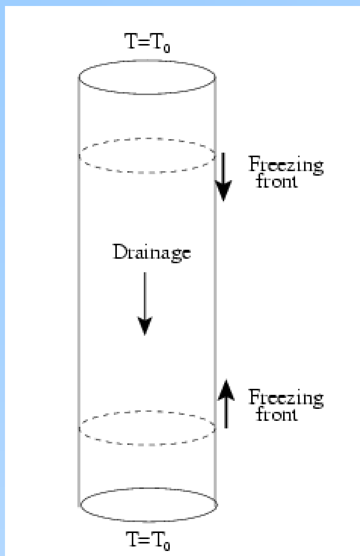
source: Banhart, Proc. Eufoam 2000

Powder metallurgical route

Foaming stage:

- Heat mixture to melting point of metal, when (carefully chosen) blowing agent releases gas.
- Cool rapidly to solidify closed-cell foam while retaining homogeneity.

A little modelling



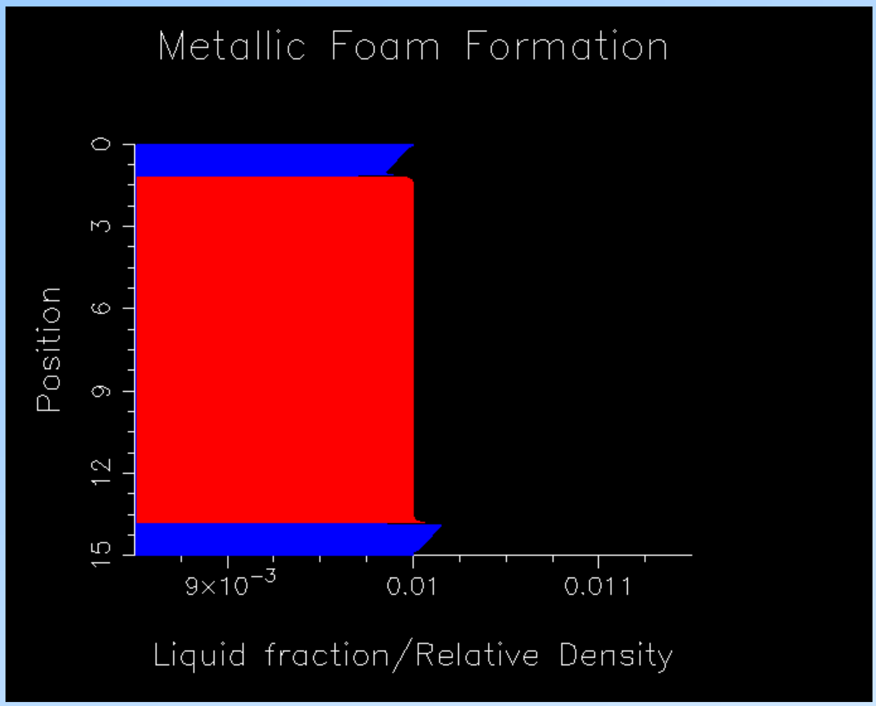
•At any point in the freezing process the foam is molten in the centre and solid around the outside.

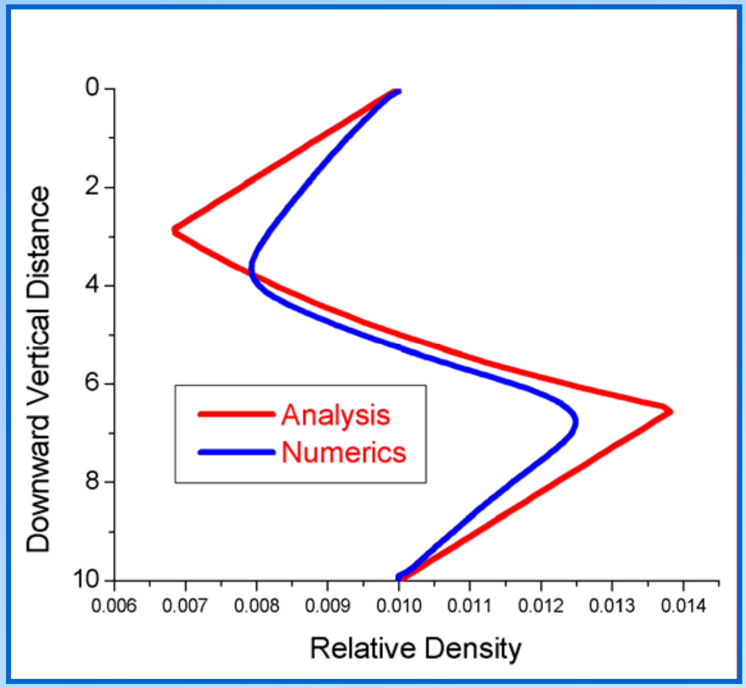
•If the foam is cooled too slowly, gravity-driven liquid drainage will reduce the amount of liquid in the centre of the foam, leading to inhomogeneity and collapse.

•Model the freezing and drainage process by allowing the liquid viscosity to depend upon temperature.

•Doesn't describe bubble nucleation.

•Measures the relative density (and temperature distribution) over time.





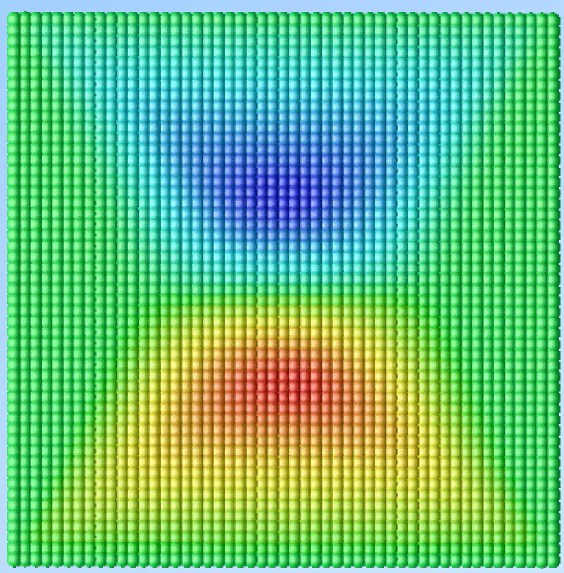
Analysis based on conservation of energy and conservation of mass gives an **homogeneity** criterion for a uniform solidified foam.

(Cox, Bradley and Weaire, *EJP:AP* **14**, 2001.)

Blue = drier

Red = wetter

Green = initial value

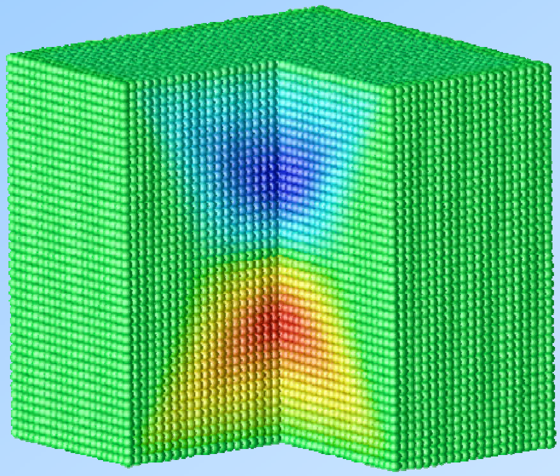


2D "Hele-Shaw" cell showing final variation of relative density.

Blue = low relative density

Red = high relative density

Green = initial value

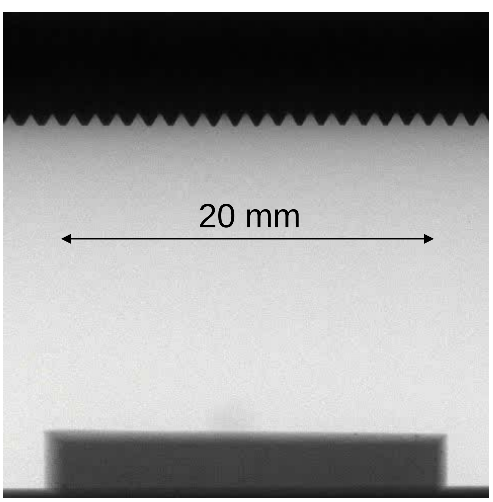


3D cubic cell, frozen from all sides

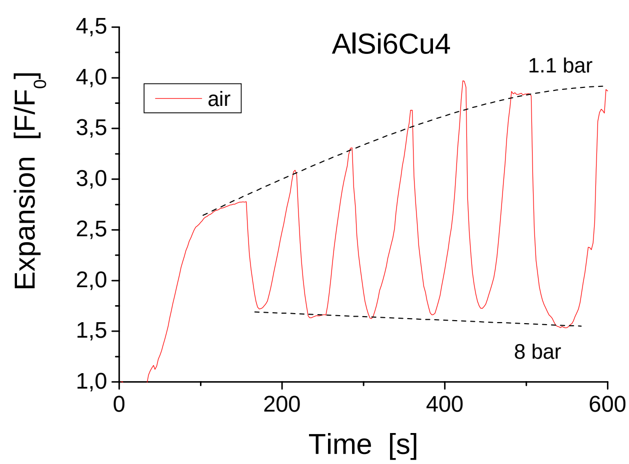
Influence of gas pressure

F. García Moreno, N. Babcsán and J. Banhart

- AlSi6Cu4 foamed under different gas pressures



Foaming in air at 1.1 bar



Foam expansion

Glass and carbon

Glass foam (e.g. SiO_2; good insulator; recyclable; powder route)

Carbon & graphite foam (e.g. from coal; range of thermal conductivities, open cell; precursor to ceramic and metal foams)

Cellular Ceramics

Benefits:

- High surface area
- High permeability
- Low mass
- High thermal insulation

Applications:

- Liquid metal filtration
- Gas (particulate) filtration
- Thermal insulation and kiln furniture
- Chemical reactors
- Porous burners
- Solar radiation conversion
- Biomedical and implant technology
- 3D interpenetrating composites
- Porous motors

source: Cellular Ceramics Structure, Manufacturing, Properties and Applications, Colombo and Scheffler (eds), Wiley (2005)

Production

Replication of polymer foams (reticulation):

•coat a polymeric foam with a ceramic slurry

•burn off polymer and harden the open cell ceramic foam (sintering).

Direct foaming with surfactant, e.g. by beating etc. (closed cell)

In situ gas evolution, as in powder route for metals. (open/closed cell)

Summary

•Many applications for lightweight solid foams.

•Development of new fabrication methods is almost purely application driven.

•In general, little modelling of processes, only testing of mechanical properties and trial and error experimentation.