Les matériaux cellulaires : les mousses métalliques

L. Salvo

SIMaP

Grenoble INP — cnrs www.cnrs.fr — Université Joseph Fourier Sciences.Technologie.Santé

Outline

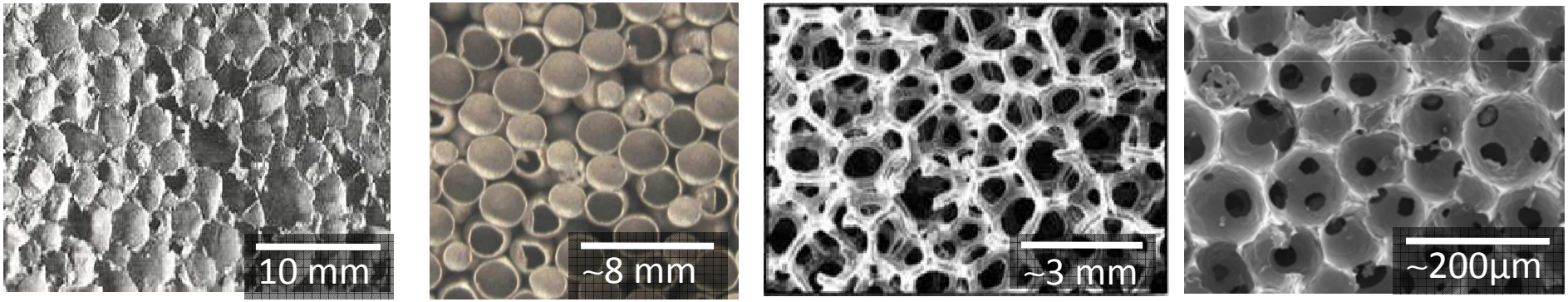
- Introduction
- Elaboration
- Mechanical properties
- “Material by Design”
- Conclusion

Metal foams are highly porous materials

- **Relative density :** $\frac{\text{Foam density}}{\text{Constitutive material density}}$ = [0.05 – 0.5]

- **Architecture : closed, open, mixed …**

Closed cells foam mixed Open cell foams



- **Cell size ranges from 50 µm to several cm**

US Patent No. 2,434,775, B. Sosnick, 1948

Alloy mixing

Cellular Materials: New Concepts Provide Unique Possibilities, The Iron Age, Article Feb, 1962.

Salt preform infiltration

Norskhydro
Duralcan
Alporas

USA
Norvège
Angleterre

1950 1960 1970 1980 1990 2000 2010

US Patent No. 3,087,807, Benjamin C Alen *et al*, 1963

Powder metallurgy + foaming agent

US Patent No. 3,300,296, Paul W Hardy Glenn W Peisker, 1967.

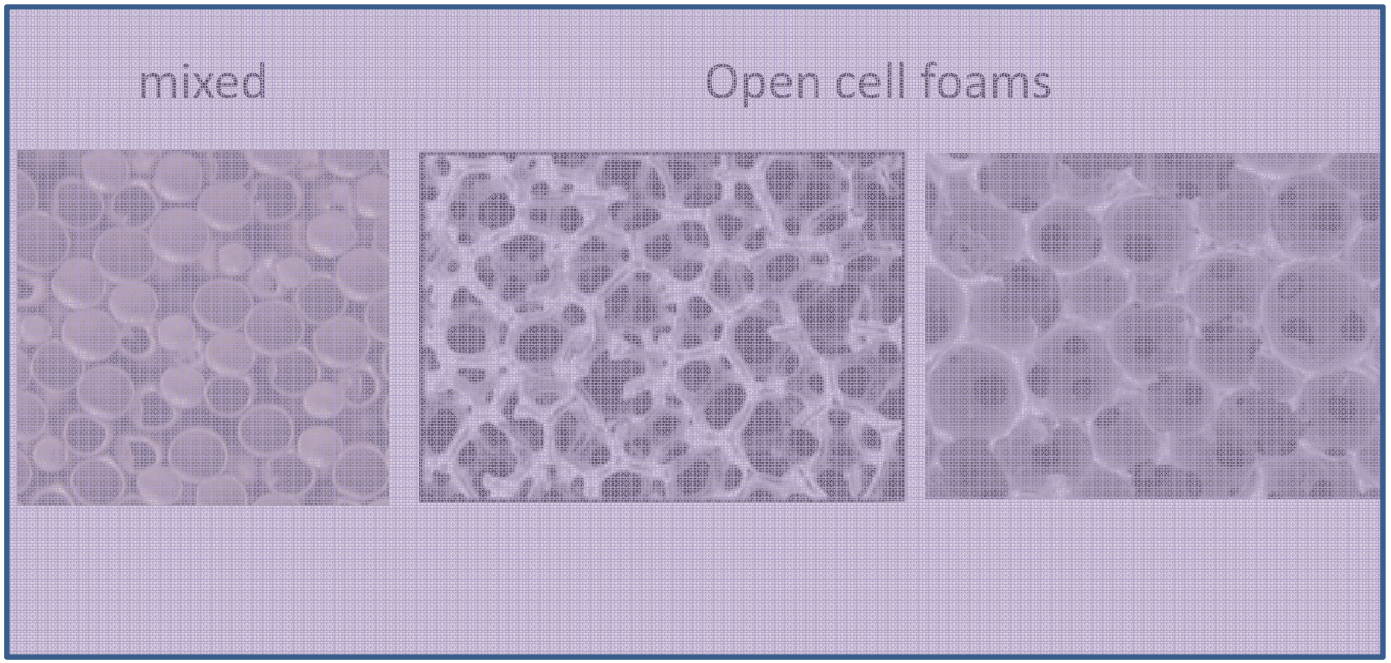
Liquid metal + foaming agent

These foams are exciting !!

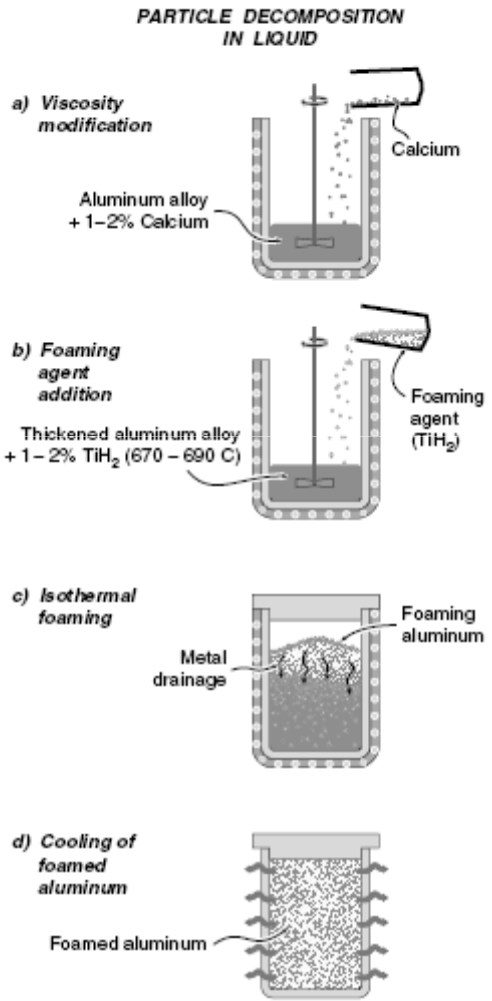
Paris, Lyon
Grenoble

Source : http://www.msm.cam.ac.uk/mmc/people/old/dave/dave.html

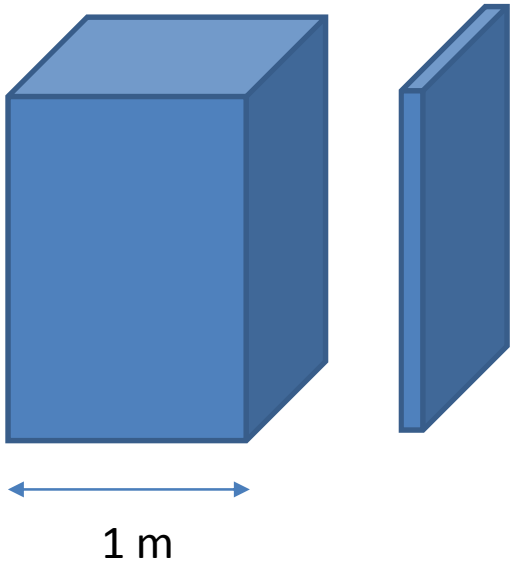
Closed cells foam

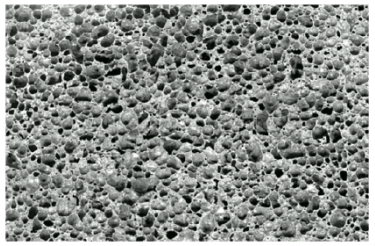


ALPORAS (Japon) : foaming agent in liquid metal



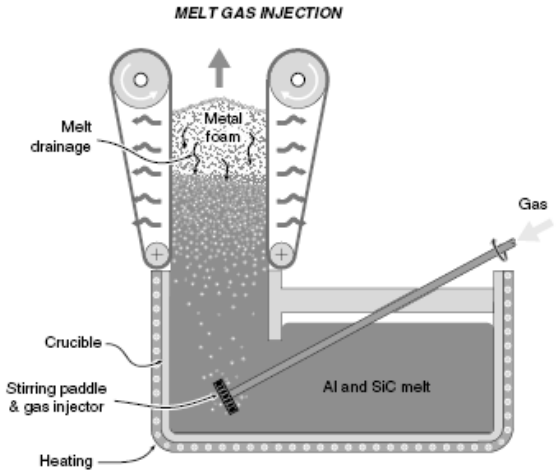
Material : Aluminium - Calcium
Relative density : 0.1 – 0.5
Closed cells large ingot
sandwich
Good reproducibility



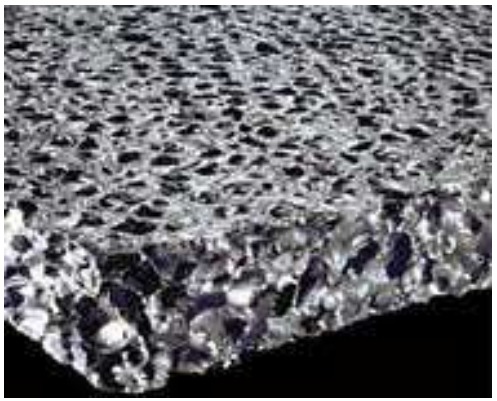


Source : metal foam a design guide : M. Ashby et al

HYDRO – CYMAT (Norvège, Canada) : gaz injection in liquid metal



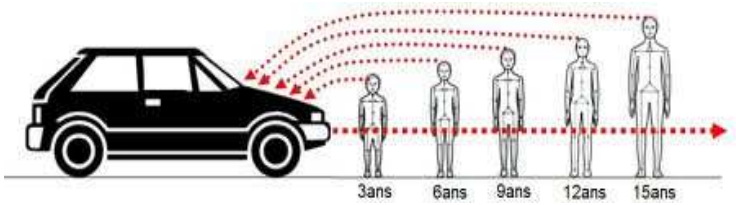
Material : metal matrix composites
Relative density : 0.1 – 0.4
Closed cells
3D shape possible
sandwich
Medium reproducibility



www.cymat.com

Source : metal foam a design guide : M. Ashby et al

HYDRO – CYMAT (Norvège, Canada)



Weight gain up to 40 %

Passive protection

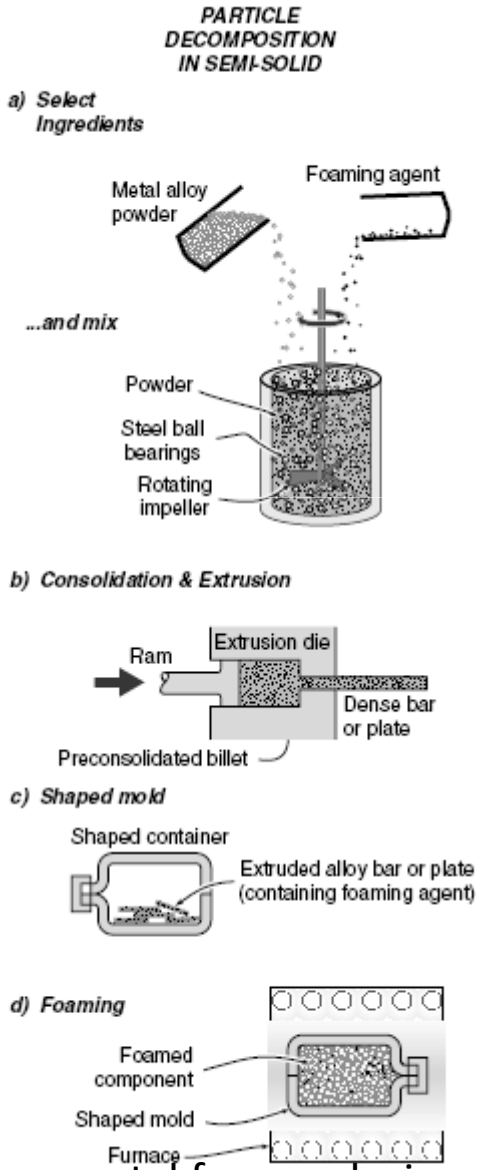
Hanssen, A.G., *Structural Crashworthiness of Aluminum Foam-Based Components*, Ph.D. Thesis, Norwegian University of Science and Technology, June 2000.

www.cymat.com

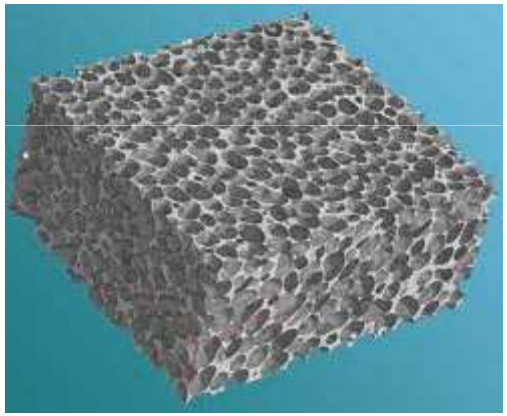
Bellora, V.A., Krauss. R., and Van Poolen, L., "Meeting Interior Head Impact Requirements: A Basic Scientific Approach", SAE Technical Paper Series: *Progress in Safety Test Methodology* (SP-1596), 2001.

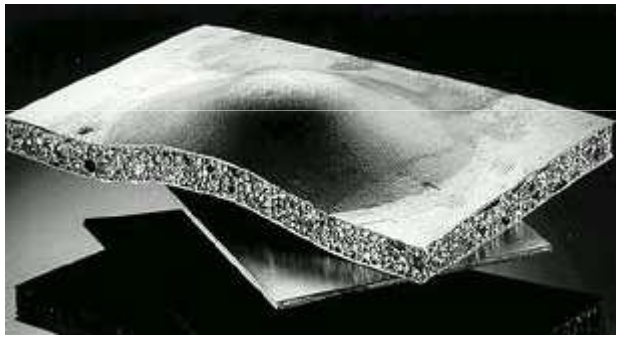
Elaboration

IFAM – ALuLight (Allemagne, Autriche) : powder metallurgy + foaming agent



Material : aluminium alloys
Relative density : 0.15 – 0.5
Closed cells in plate form
Shaping possible
Good reproducibility

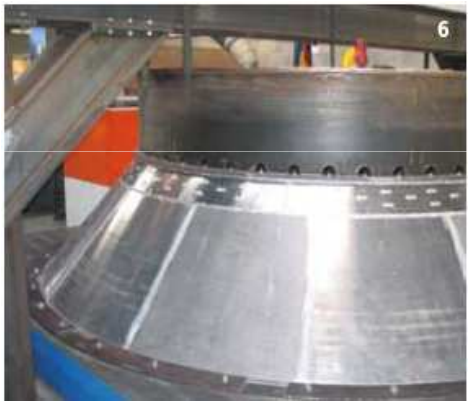




www.metal-foam.de

Source : metal foam a design guide : M. Ashby et al

IFAM – ALuLight (Allemagne, Autriche)



www.metal-foam.de

Elaboration

US Patent No. 2,434,775, B. Sosnick, 1948

Alloy mixing

Cellular Materials: New Concepts Provide Unique Possibilities, The Iron Age, Article Feb, 1962.

Salt preform infiltration

Norskhydro
Duralcan
Alporas

USA
Norvège
Angleterre

"New" Elaboration technique

Architecture
Control
Reproducibility

1950 1960 1970 1980 1990 2000 2010

US Patent No. 3,087,807, Benjamin C Alen *et al*, 1963

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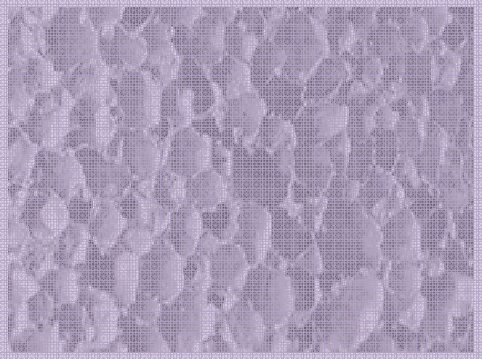
US Patent No. 3,300,296, Paul W Hardy Glenn W Peisker, 1967.

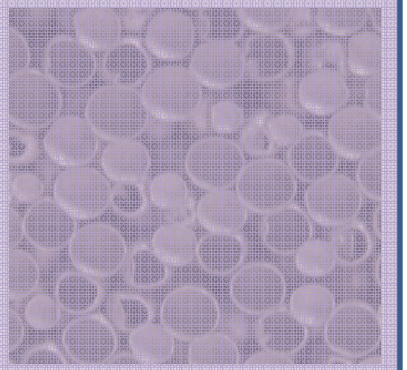
Liquid metal + foaming agent

Source : http://www.msm.cam.ac.uk/mmc/people/old/dave/dave.html

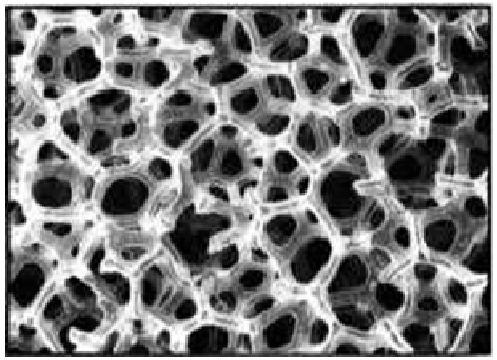
Closed cells foam

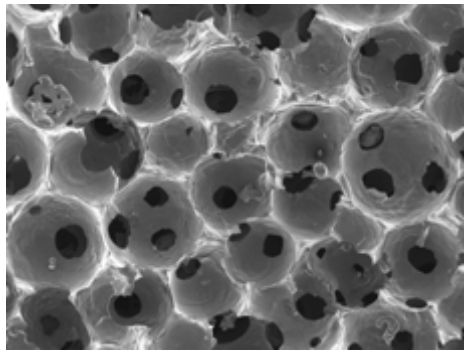


mixed



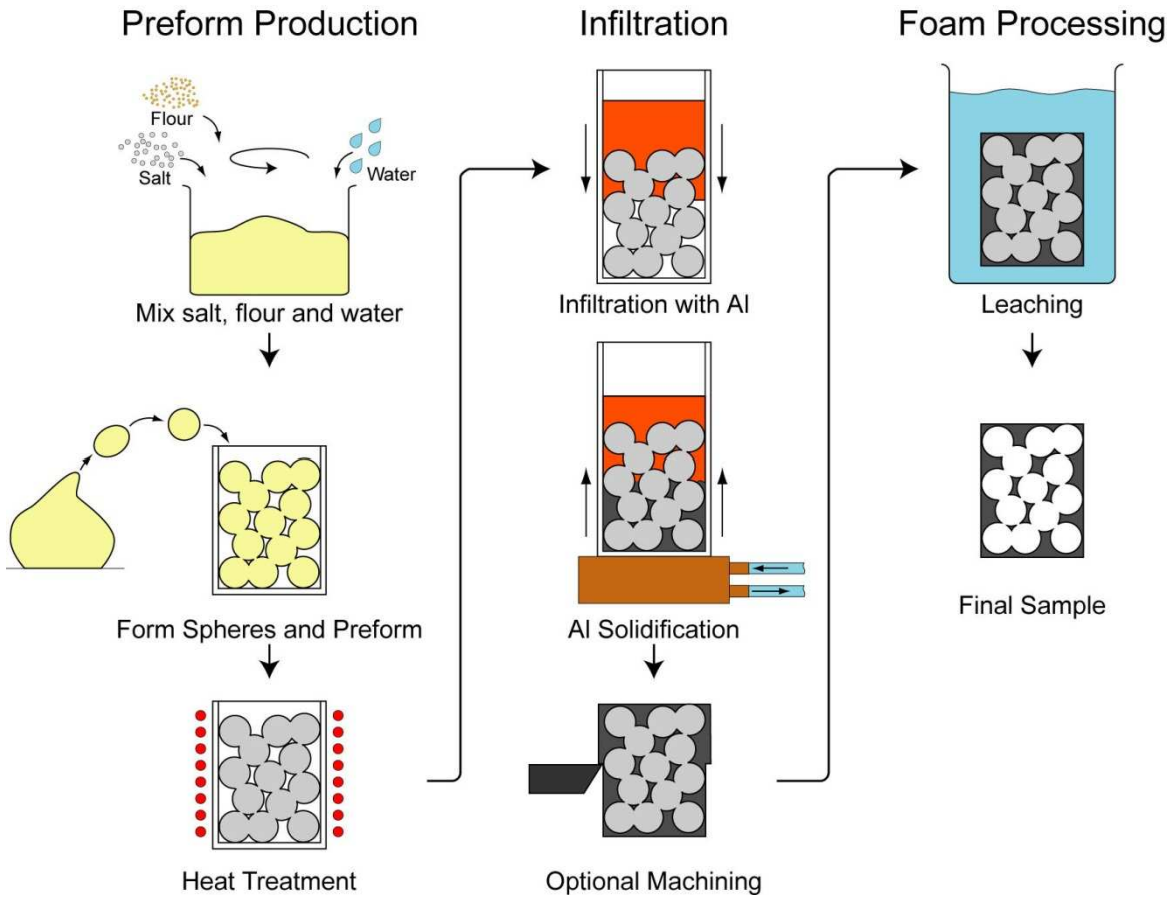
Open cell foams





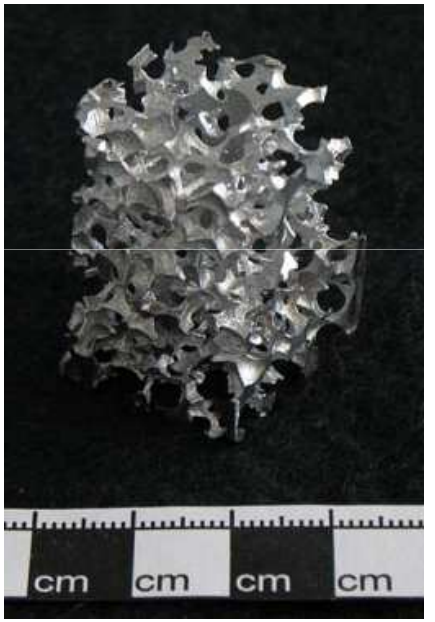
Elaboration

EPFL / Constellium : like salt preform infiltration



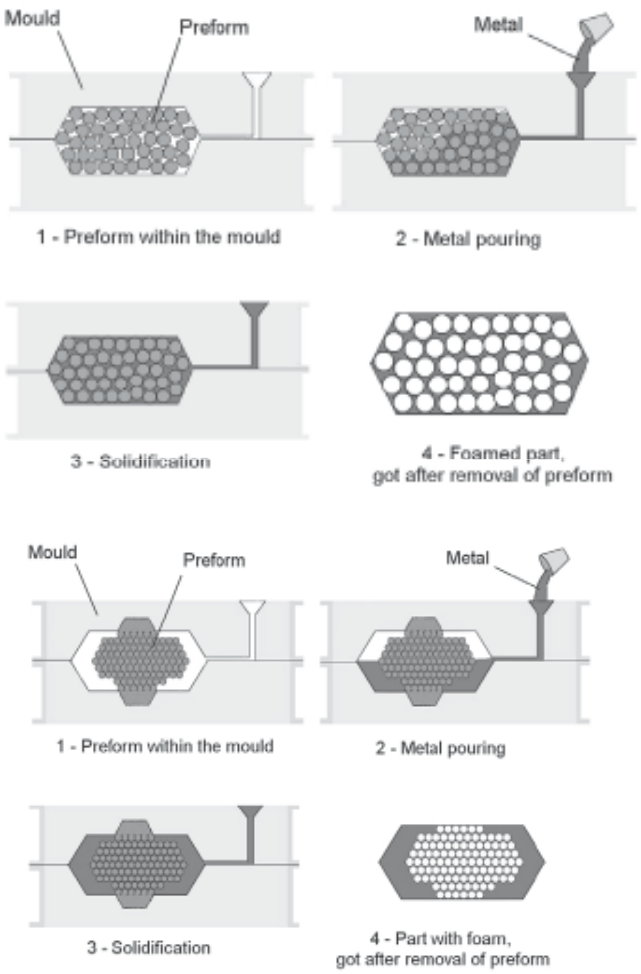
R. Goodall and A. Mortensen, "Microcellular Aluminium? - Child's Play!", *Advanced Engineering Materials,* vol. 9 (11), pp. 951-954 (2007).

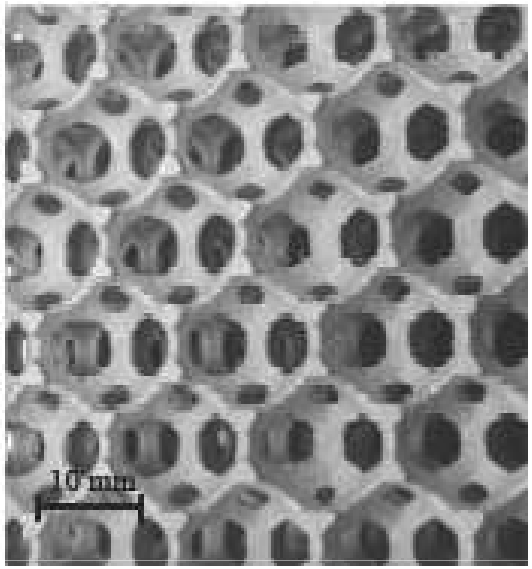
Fast dissolution
Various preform morphology
…..



Material : aluminium alloys
Relative density: 0.1 – 0.4
Open cell foams
Various architecture
Very good reproducibility

CTIF : like salt preform infiltration (CASTFOAM)

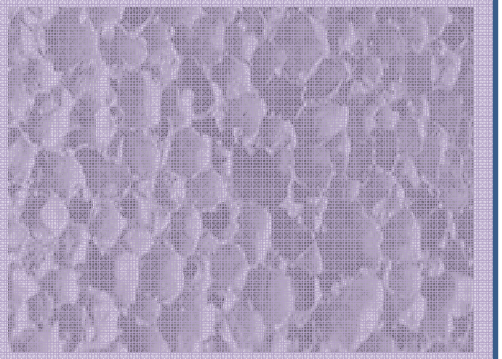




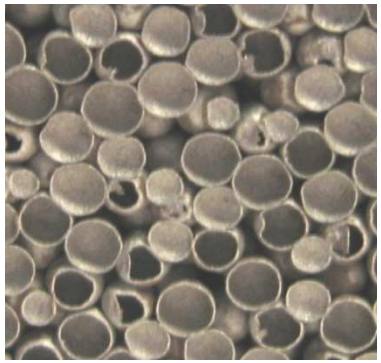
Material : cast alloys
Relative density : 0.1 – 0.4
Open cell foams
Architecture control
Very good reproducibility

J. Dairon, Y. Gaillard, J.-C. Tissier, D. Balloy, G. Degallaix, « Parts containing open-celled metal foam manufactured by the foundry route: Processes, performances and applications », Advanced Engineering Materials 13, (2011).

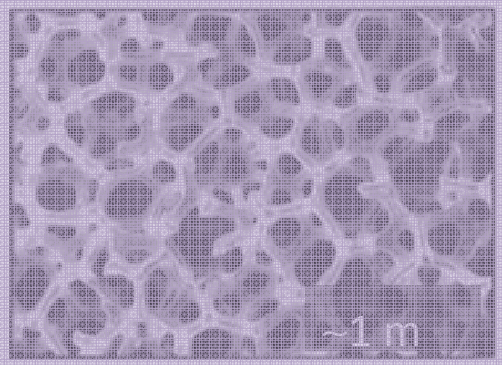
Closed cells foam

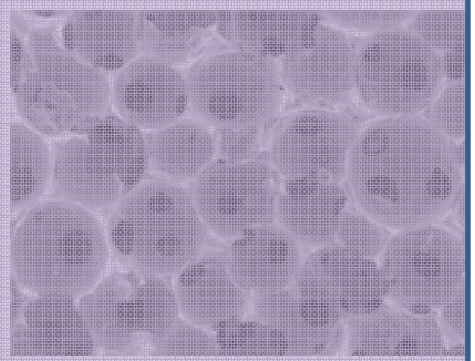


mixed

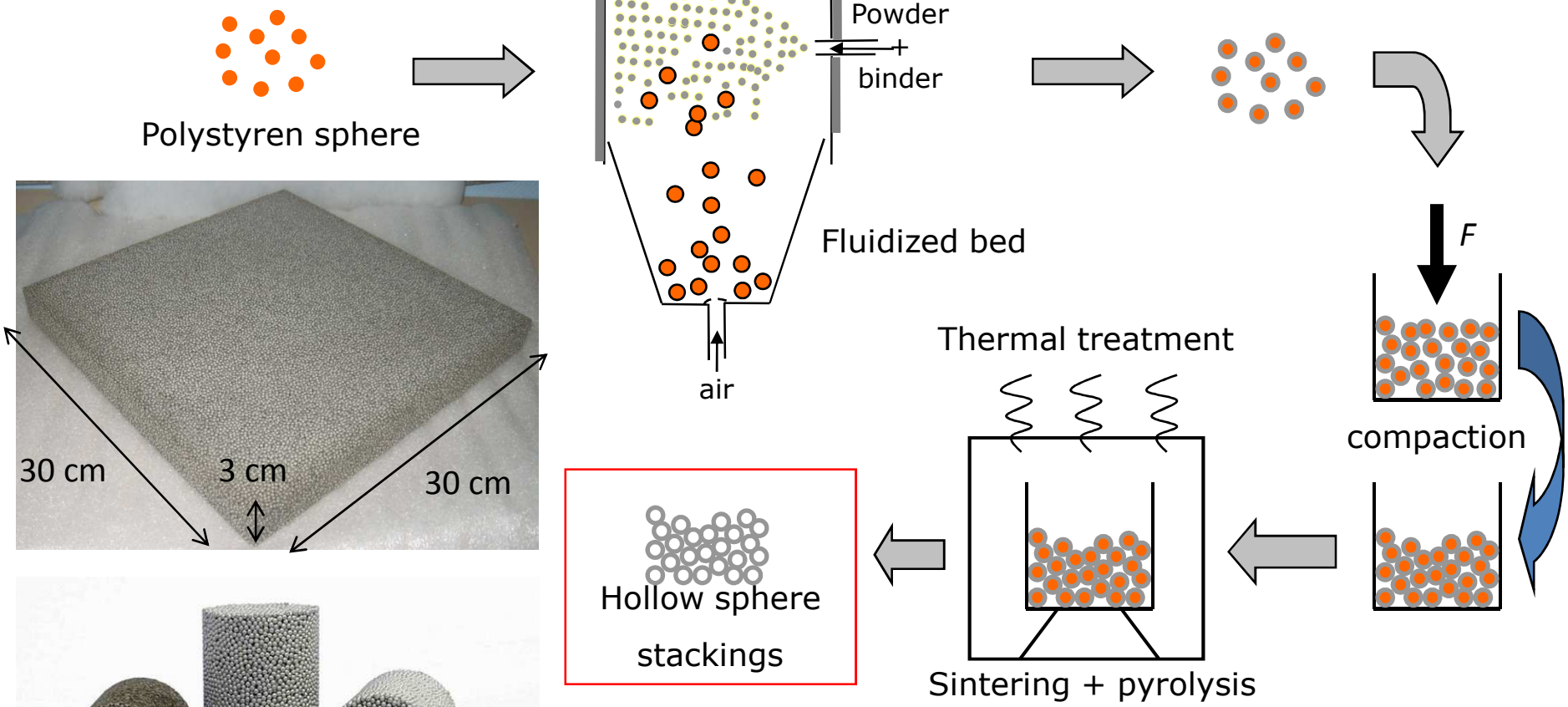


Open cell foams



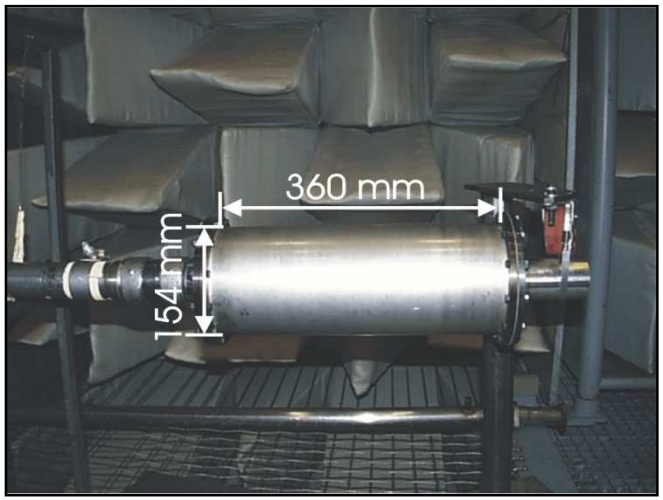


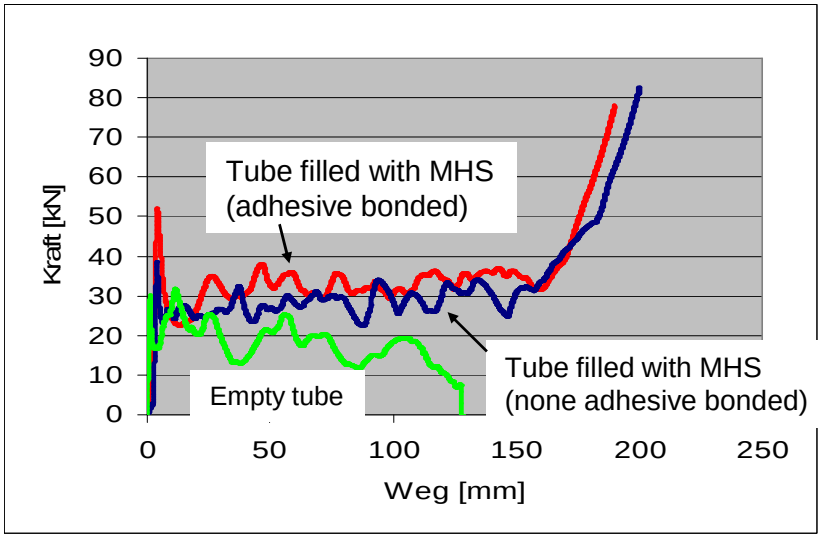
PLANSEE (Austria)

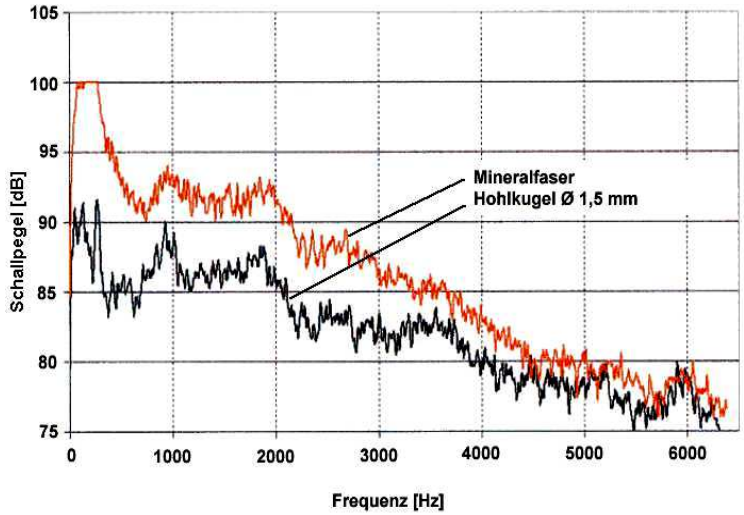


Materail : stainless steel
Relative density : 0.05 – 0.3
Architecture control
Very good reproducibility

PLANSEE (Autriche)







Fraunhofer IFAM Institut Fertigungstechnik Materialforschung

DAIMLERCHRYSLER

ZS ZEUNA STÄRKER

Glatt GmbH Systemtechnik

PLANSEE

Outline

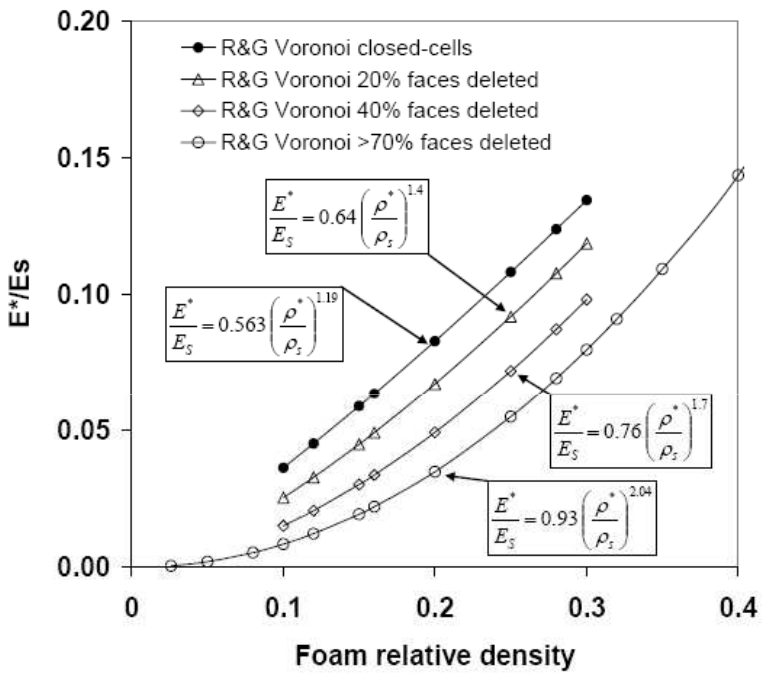
- Introduction
- Elaboration
- Mechanical properties
- “Material by Design”
- Conclusion

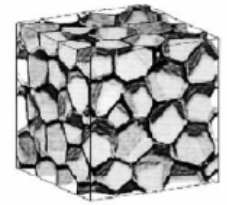
Mechanical or physical properties follow scaling laws

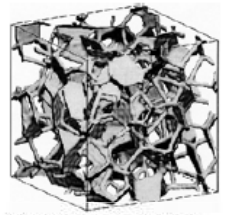
$$\frac{P^*}{P_S} = A\left(\frac{\rho^*}{\rho_s}\right)^n$$

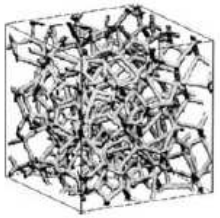
P* : property of the foam
P_s : constitutive material property
ρ* : density of the foam
ρ_s : density of the consitutive material

[roberts 2001]




closed-cell


20 % faces deleted

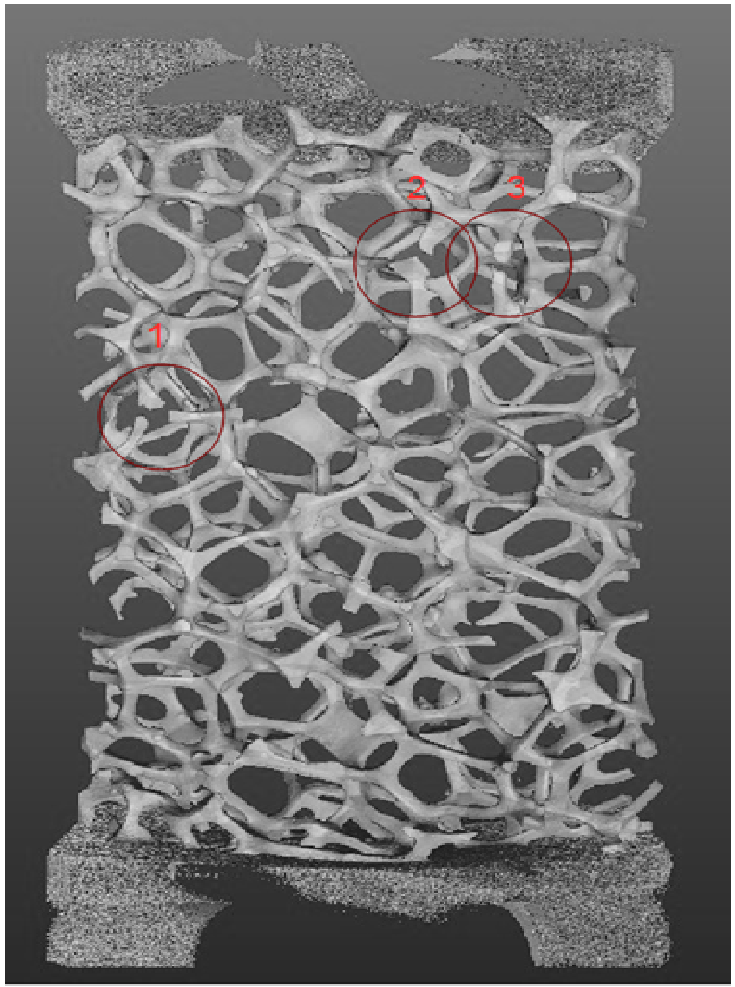

> 70 % faces deleted

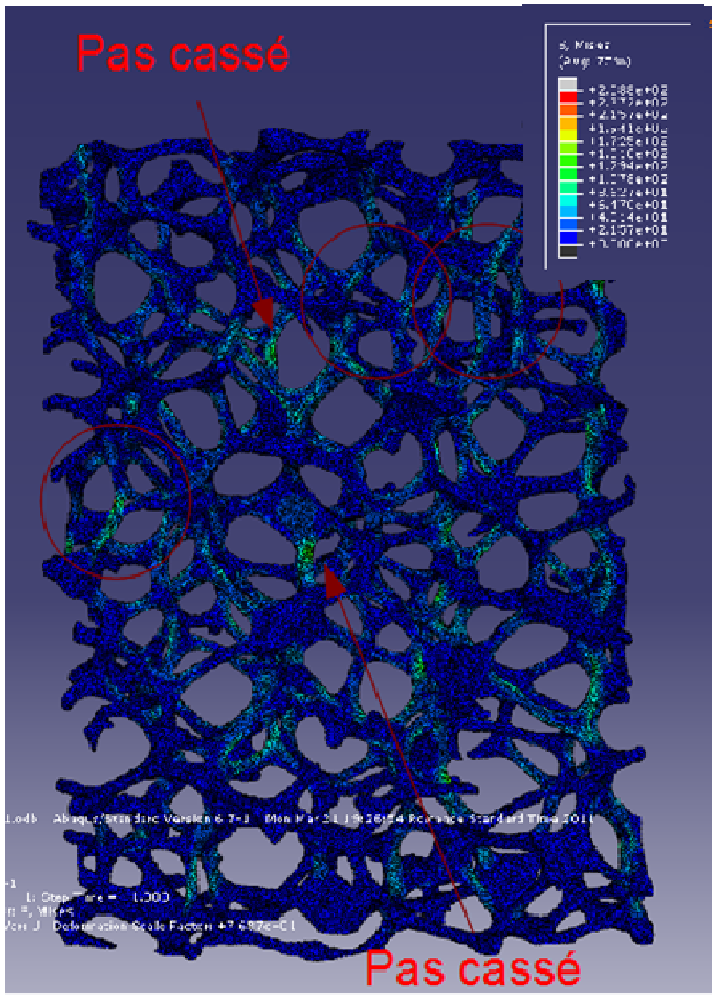
But differences between simulatin/experiments

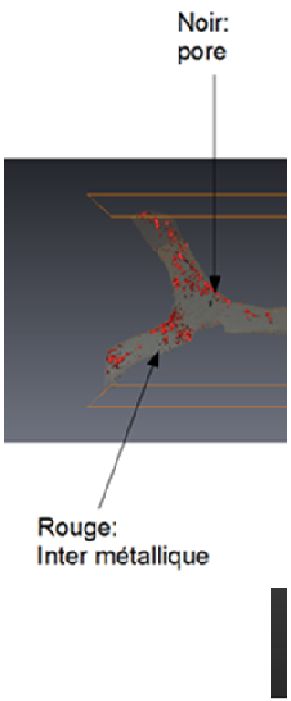
Numerical microstructures / model is not representative of real foam → Tomography + simulation (E.Maire, S. Forest)

Ps is generally not well known → Metallurgy (very few studies …)

Tensile behaviour of an ERG foam [Zhang et al AEM 2013]







Microstructural information is needed at the struts level

Outline

- Introduction
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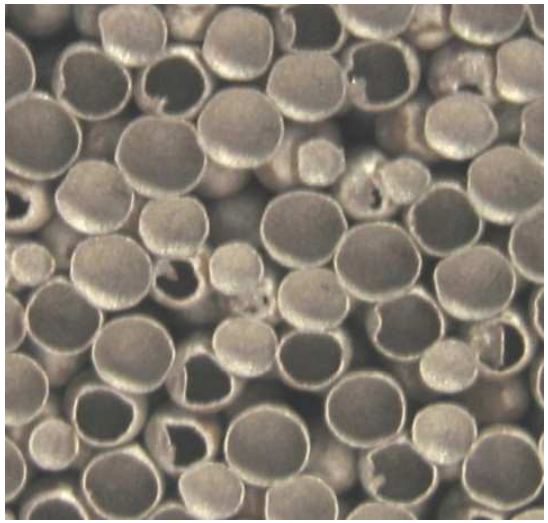
Architecture control : large number of degree of freedom

⇒ « Material By Design »



Closed cells : mechanical

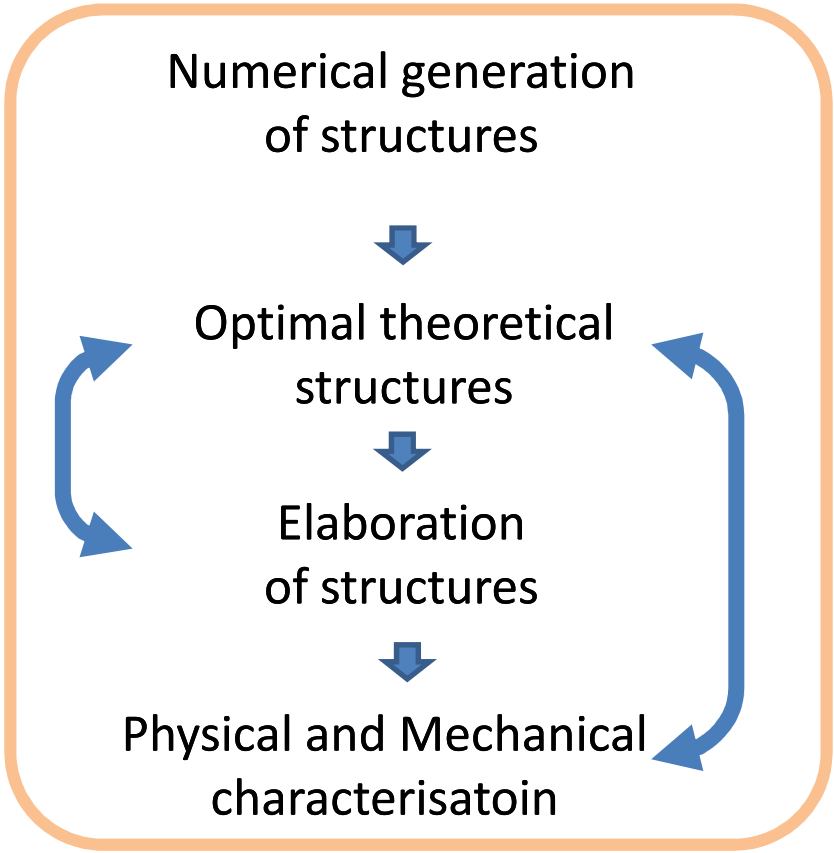
Open cells : acoustic

Sphere size ?

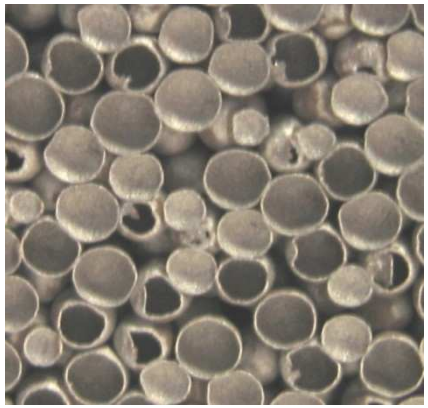
Thickness ?

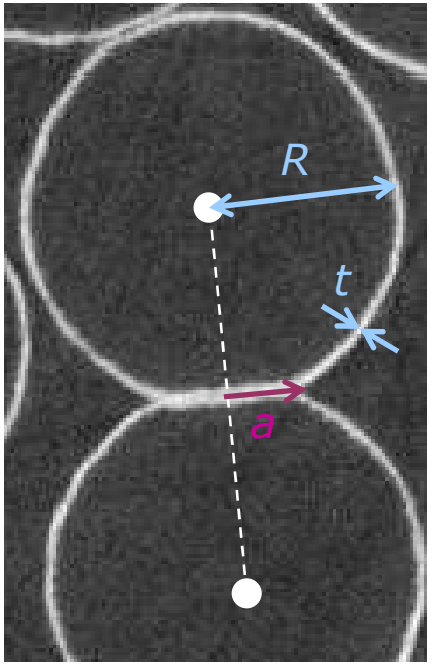
Density ?

Contact size ?

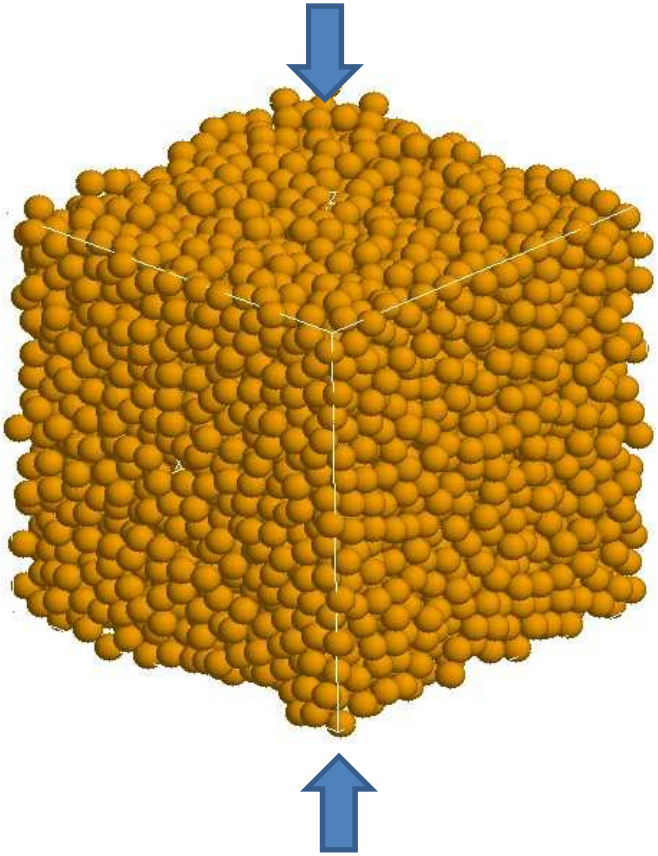


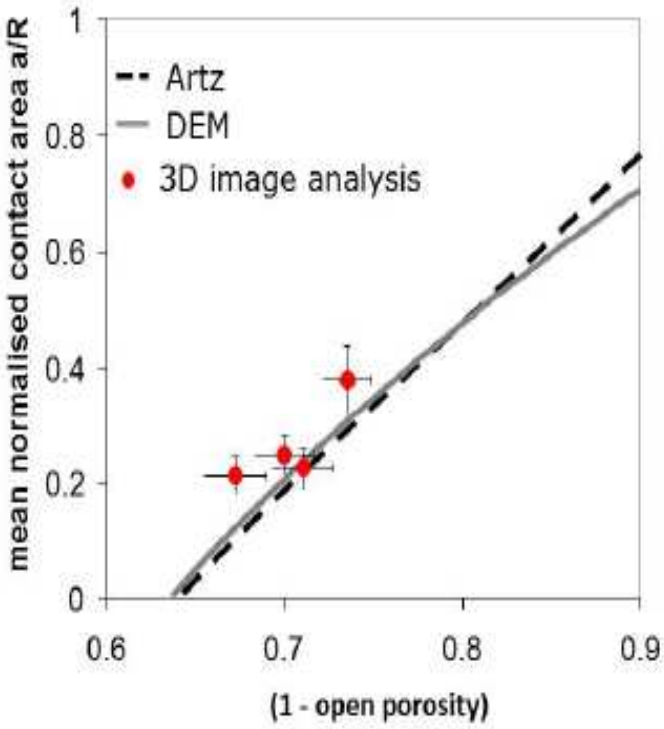
Programme ASTRA CNRS /ONERA (2006-2010)





Numerical compaction (DEM)

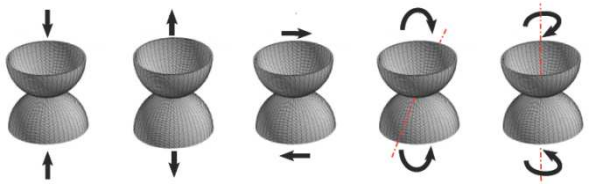




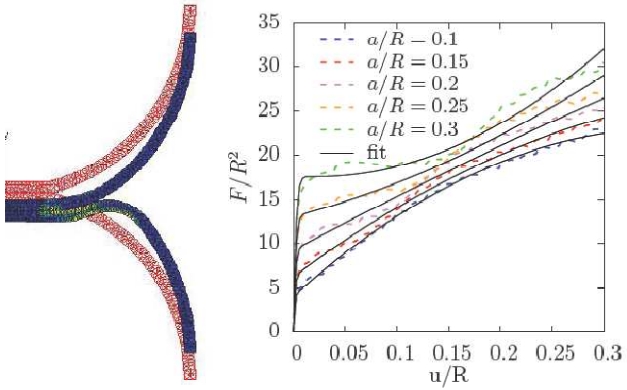
Is it representative of real hollow sphere packing ?

YES

Lois de contact avec Eléments finis

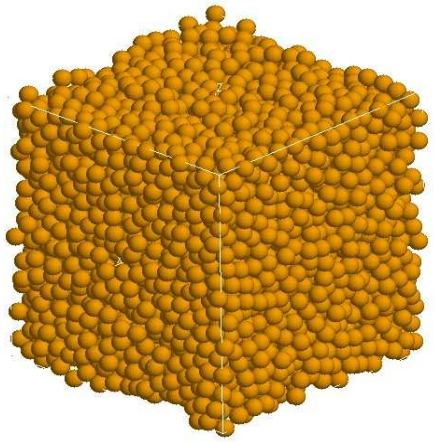


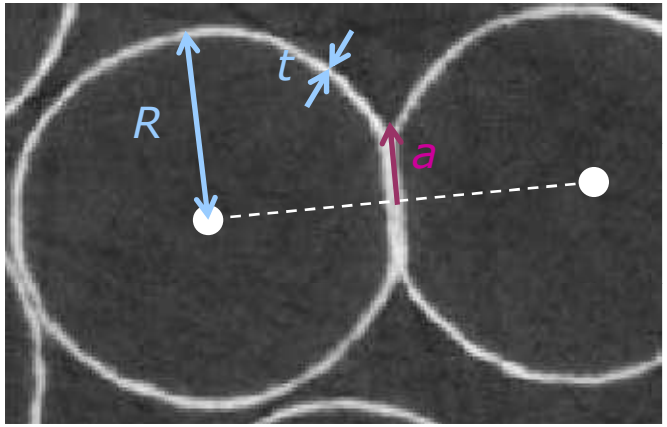
FEM



Code dP3D (C. Martin)

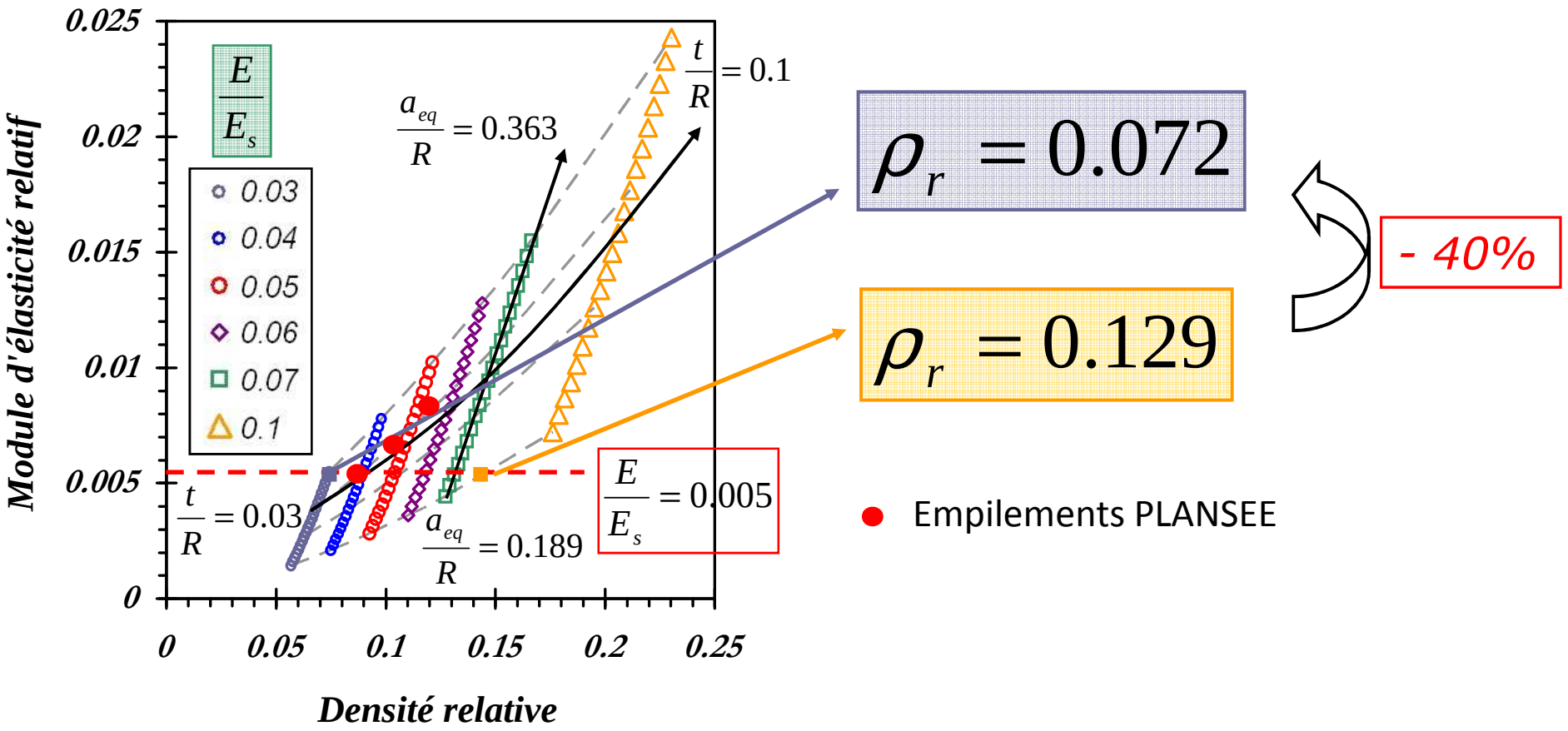
DEM





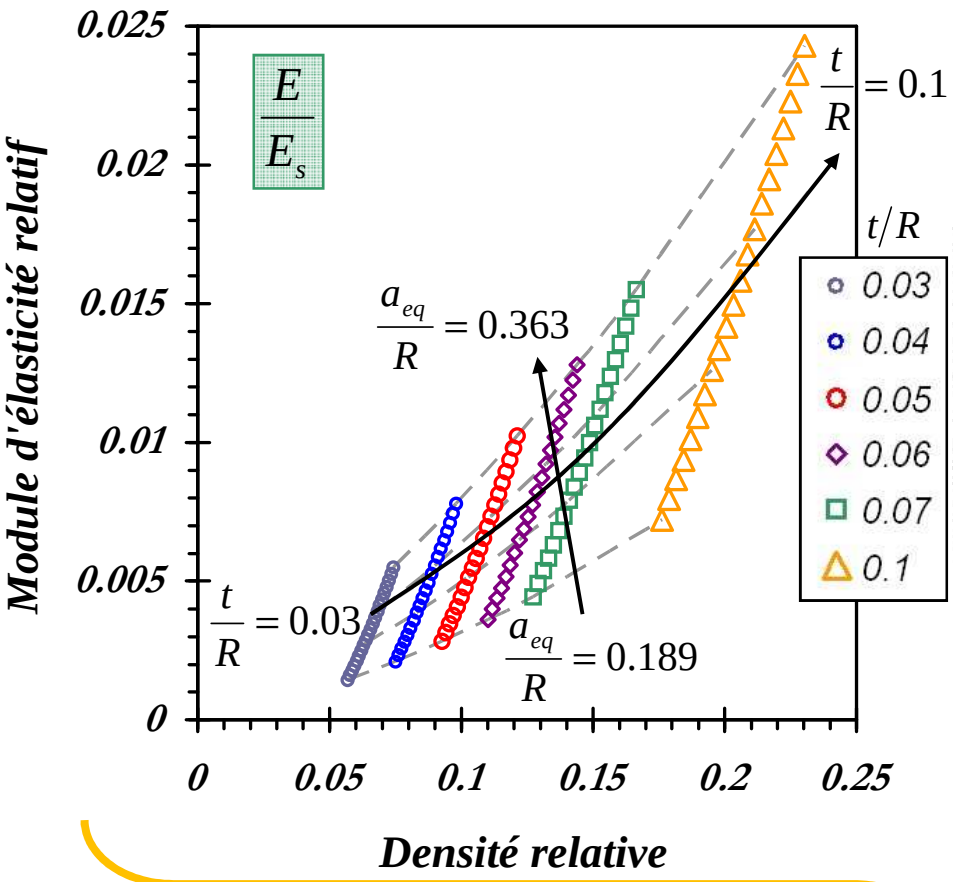
Module d'Young = f(a/R, t/R)

Limite d'élasticité = f(a/R, t/R)

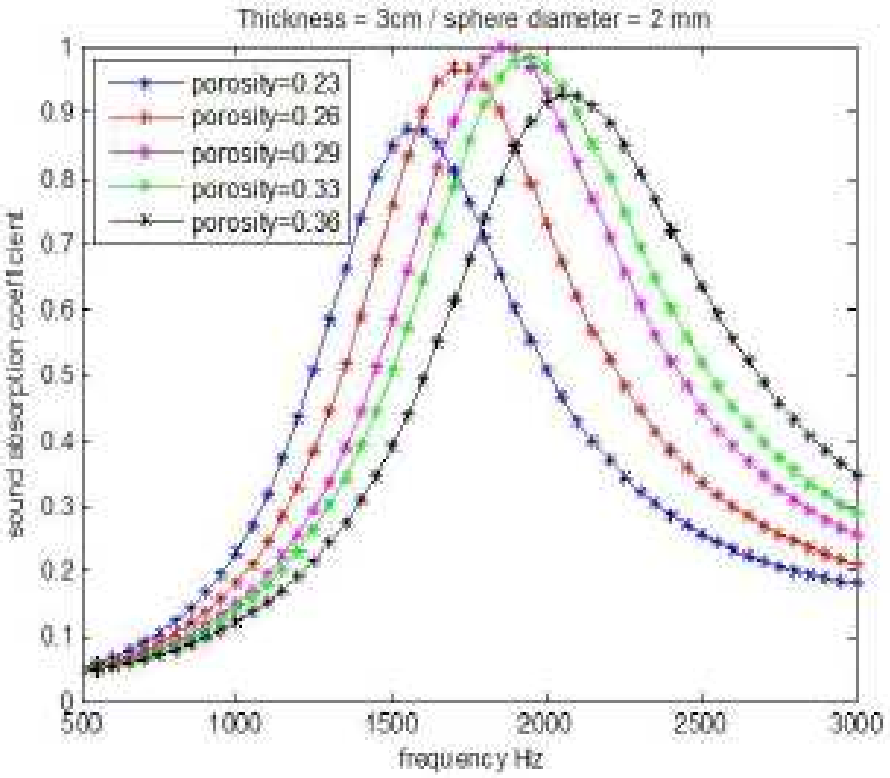


1) It is better to increase contact between sphere than increase thickness
2) Possible gain on the real structure (PLANSEE)

Mécanique (FEM+DEM)



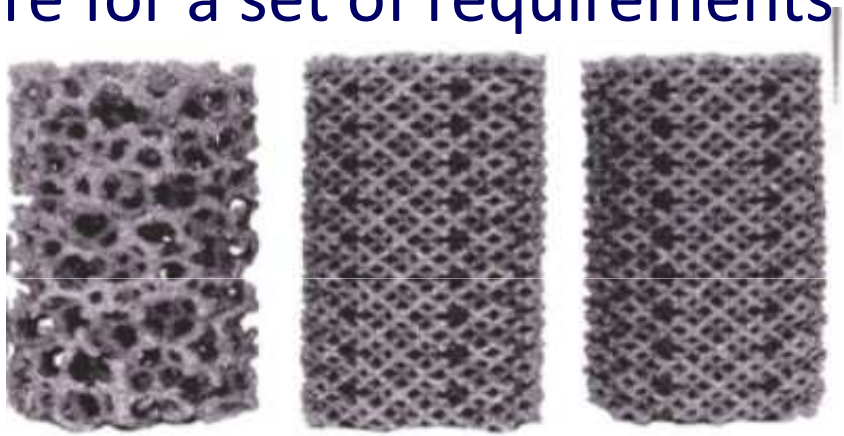
Acoustique (GEODICT)



3) Weight gain of 20% possible if acoustic is taken into account

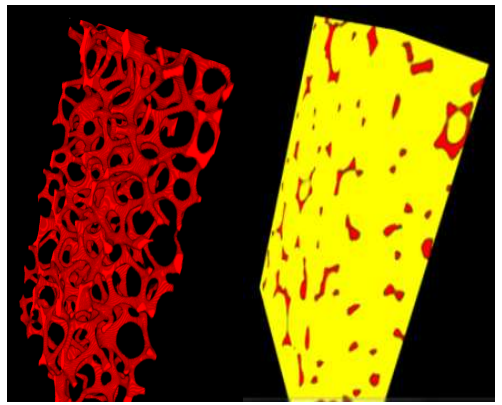
[Fallet et al scripta mat 2012]

- Lack of microstructural information in modelling or numerical simulation
- New foam processes allow architecture control (but which structure for a set of requirements ?)

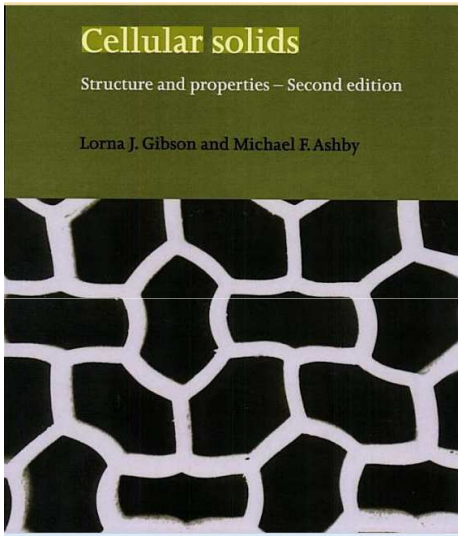


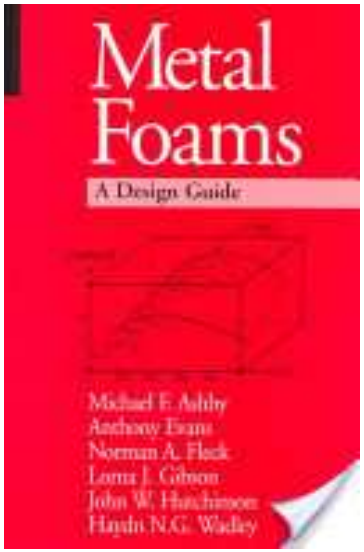
- Material substrate for multifunctionnal application (energy, building, bio …)

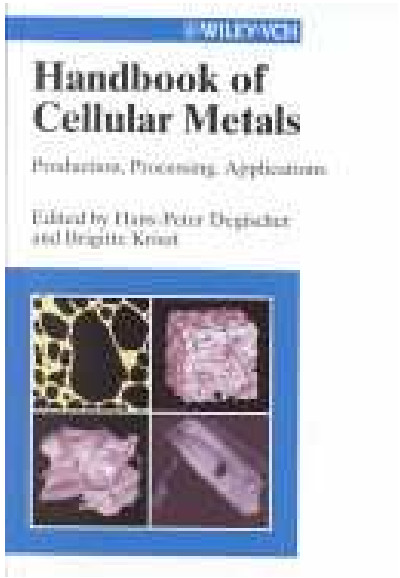
Material by design coupled with multi resolution tomography may help

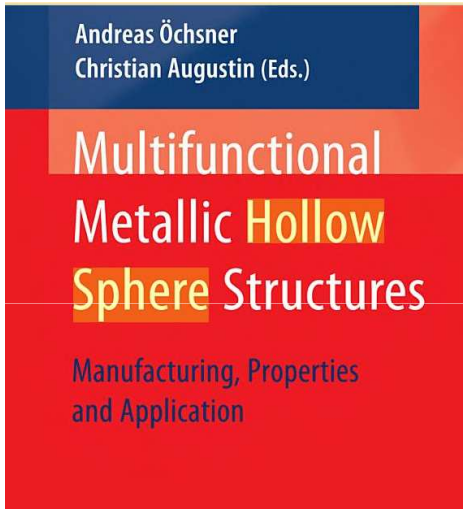


To know more about cellular solids and metal foam ….









Aknowledgements

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And you for your attention …..