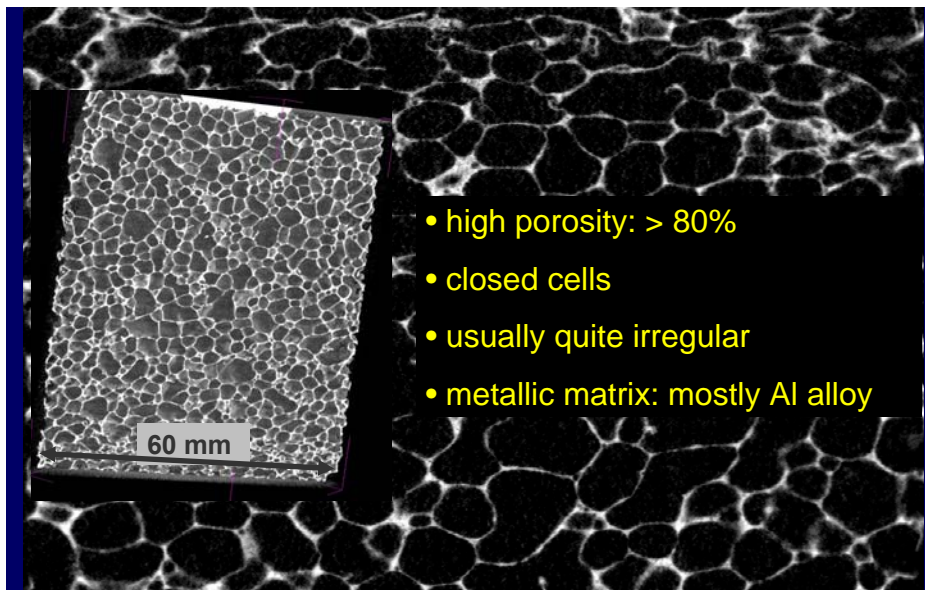


Metallic Foams II: Properties and Applications

John Banhart

1

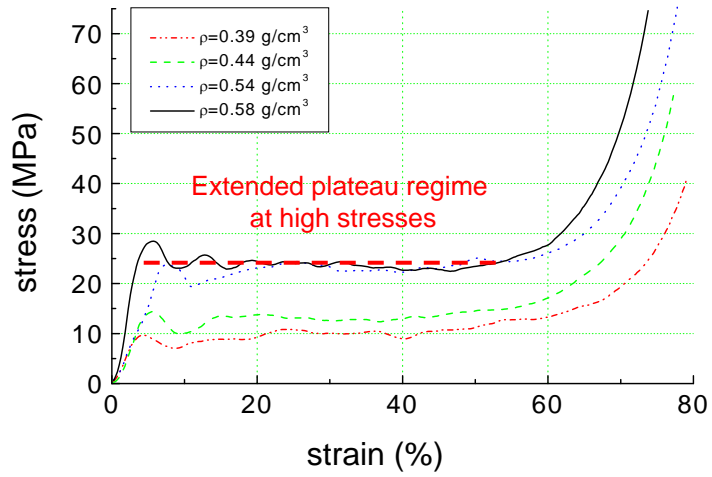
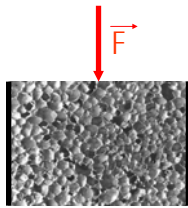


Properties

Properties of cellular metals - overview

| class | Property | Observable | | |
|------------------------------|-----------------------|------------------------------|-----------------------------------|------------------------------|
| mechanical | Elastic behaviour | Young's modulus | E | |
| | | Shear modulus | G | |
| | Anelastic behaviour | Loss factor | η | |
| | Plastic behaviour | Compressive/tensile strength | } static/ dynamic | σ_c |
| | | Shear strength | | σ_t |
| | | Bending strength | | σ_b |
| | Energy absorption | | E_{abs} | |
| electrical | Electrical conduction | Electrical conductivity | σ | |
| thermal | Thermal expansion | Expansion coefficient | α | |
| | Thermal conduction | Thermal conductivity | κ | |
| acoustic | Sound absorption | Sound absorption coefficient | $\alpha(v)$ | |
| aero- / hydro-dynamic | Flow properties | Filter parameters | α, β | |

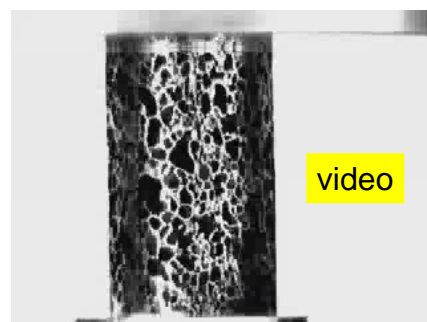
- AlSi6Cu4 foams
- varying density
- 40 x 40 x 40 mm³
- 2 face sheets

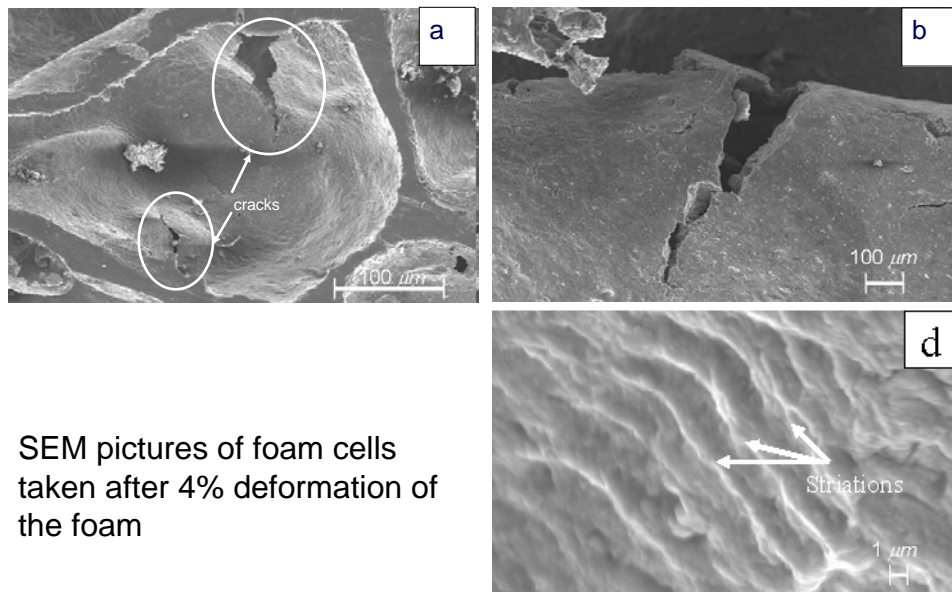
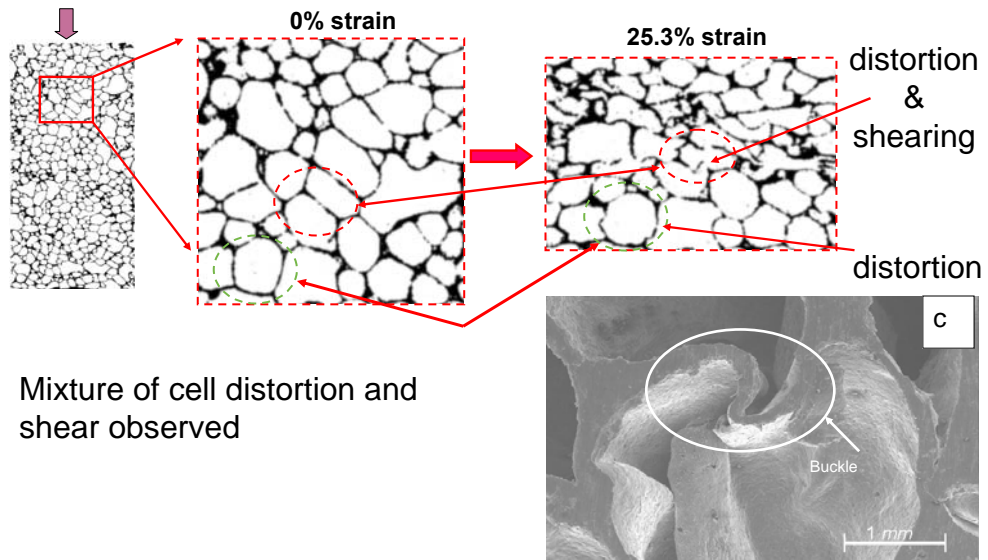


Ductile foam



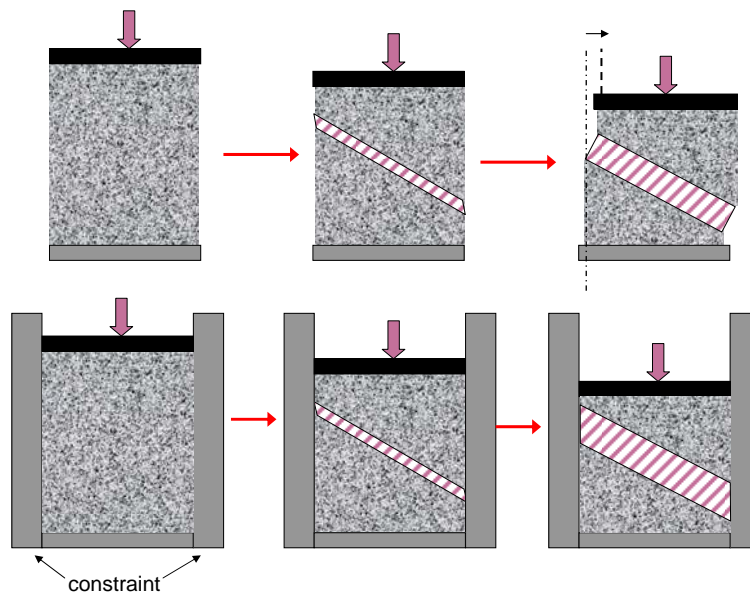
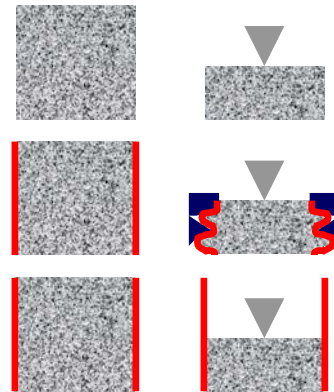
Brittle foam

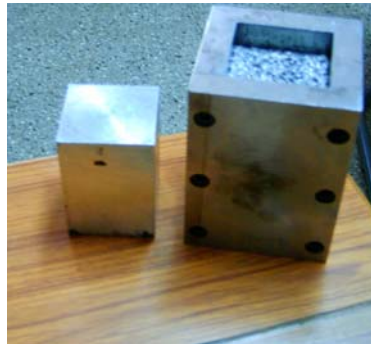




■ Foams can be loaded in three principal modes:

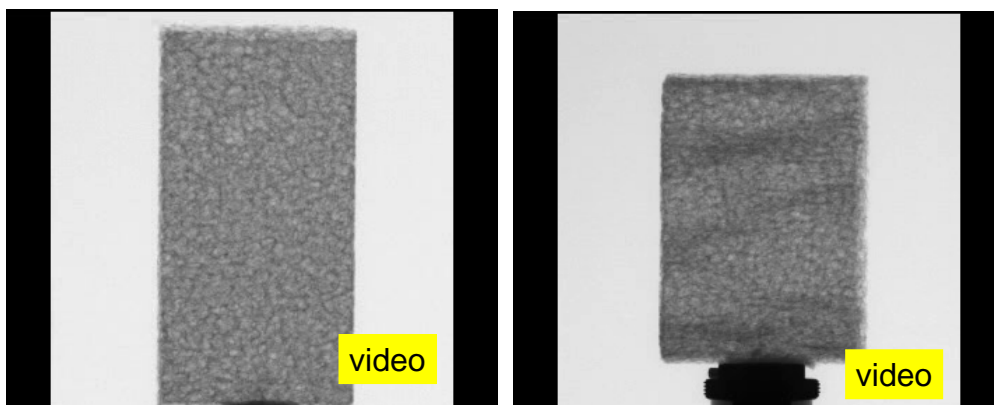
- Free foam
 - Some studies available: see Ashby book and more recent papers
- Foam in conjunction with section or face sheets
 - Some studies available, see e.g. Hansen and Langseth
- Foam in section, but load only on foam: section acts as constraint only
 - No study so far





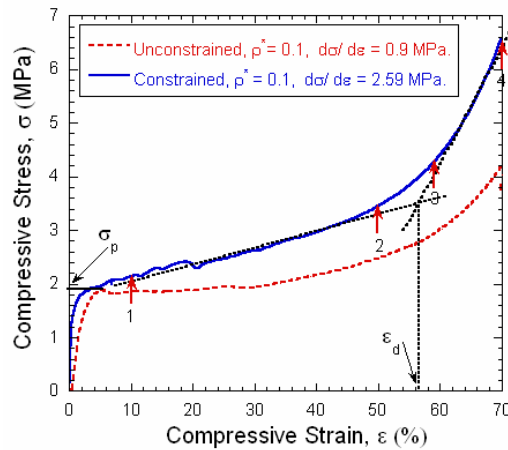
Steel sleeve (right) and aluminium block (left)
used for conducting tests with constraint

quasi-static testing with constraint



unstrained

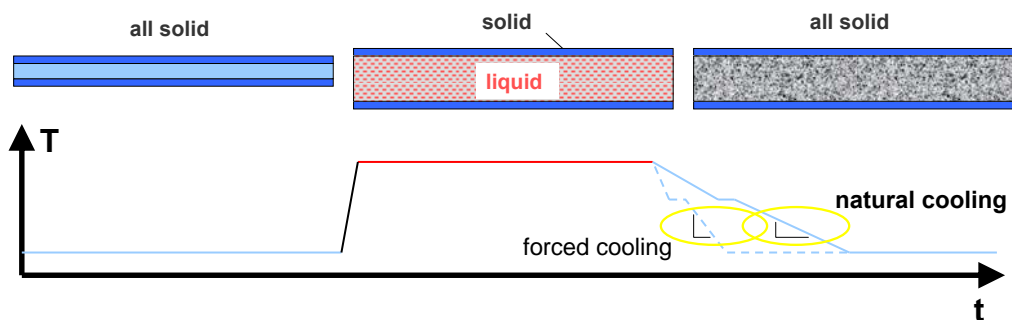
28% static strain



$\rho^* = 10.2\%$

Constraint induces **strain hardening** through
 - triaxial nature of stress
 - friction between constraint walls and foam.

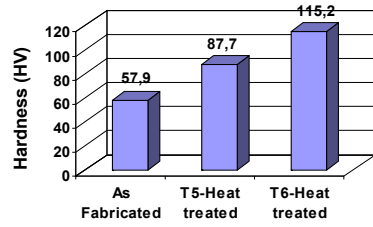
* Kolluri et al., Met. Mat. Trans 38A, 2006 (2007)



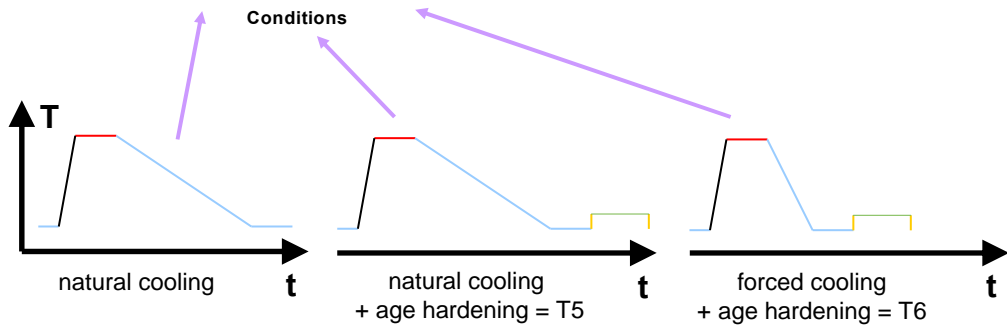
• Problem with solution heat treatment:

- heat in foam has to be conducted through face sheet
- quenching in water not feasible \rightarrow water intrusion + warping
- low quenching rate insufficient \rightarrow T6 not achievable
- question: can some degree of age hardening be reached starting from a not perfectly quenched state? \rightarrow T5

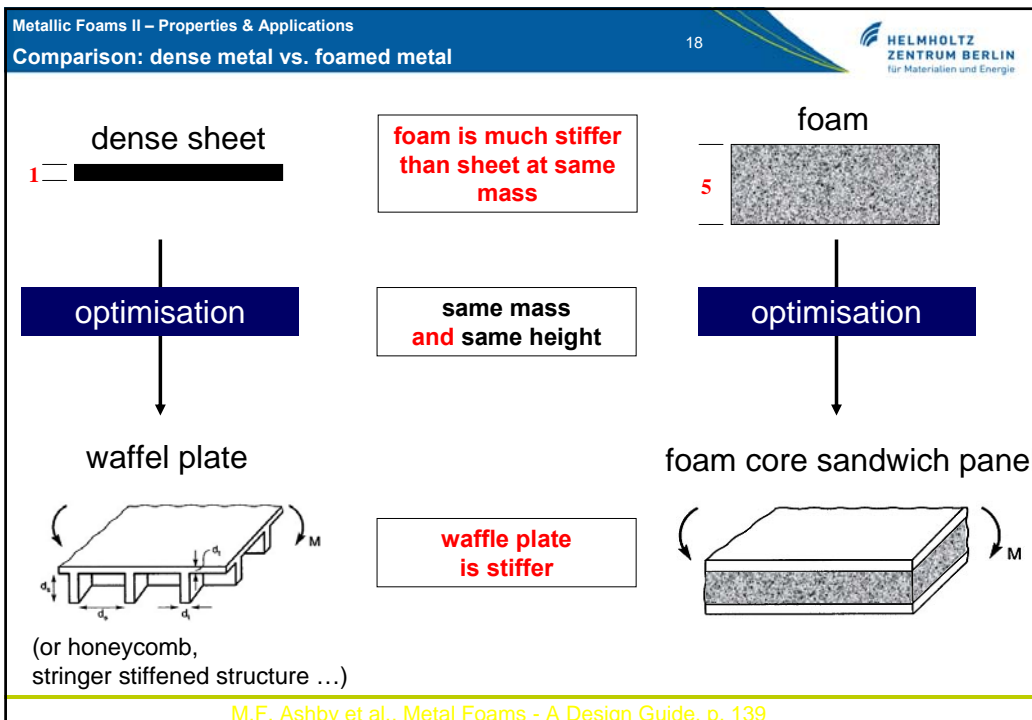
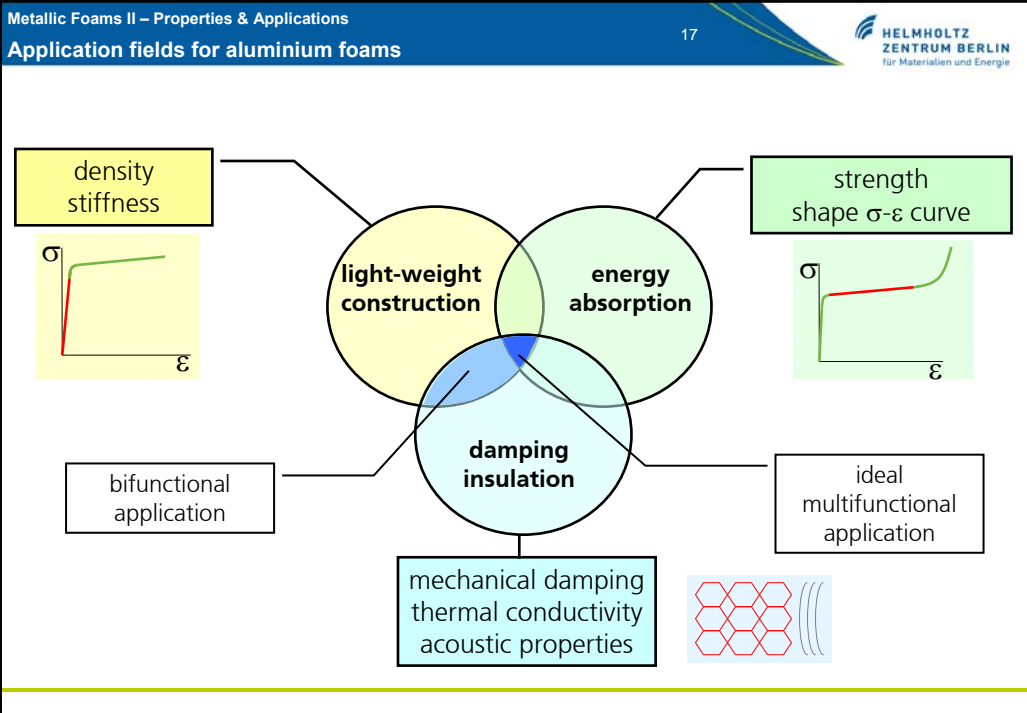
Heat treatment of AFS



- Micro-hardness
- different heat treatments
- 6082 face sheet of AFS



Applications

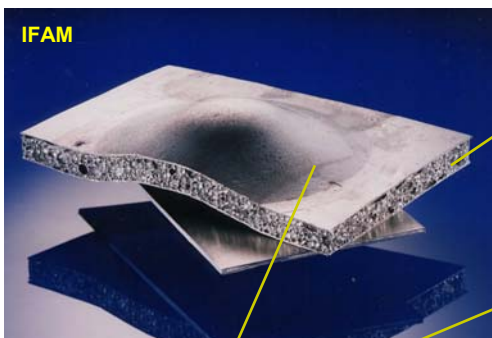


Other aspects relevant for comparison:

- manufacture of complex shapes (3D) possible
- cost
- elastic limit
- failure mode
- damage tolerance
- integration into system → joining technology
- other aspects, e.g. mechanical, acoustic electromagnetic damping ...

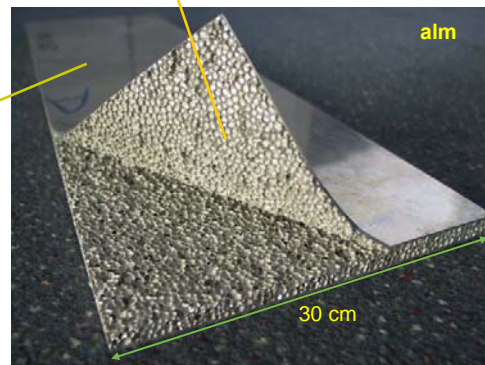


⇒ **Advantage for AFS in some cases**



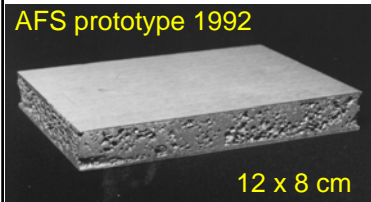
Al foam core

**dense face sheets
(Al, steel, Ti)**



AFS development

AFS prototype 1992

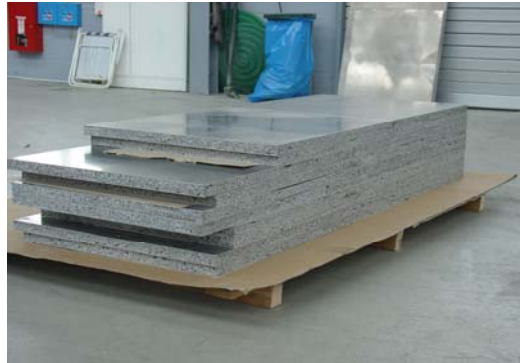


12 x 8 cm

area × 200



AFS production 2007

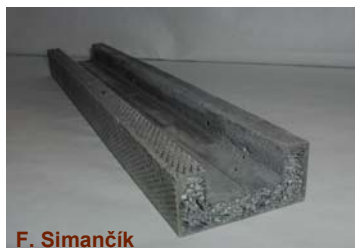


Metal foam + dense metal = composite

IFAM



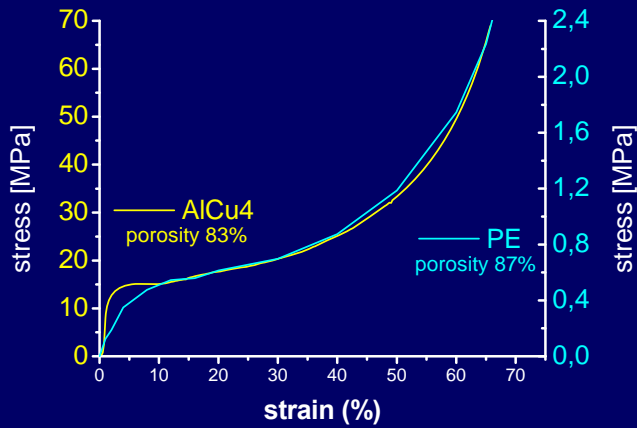
Alulight



F. Simančík

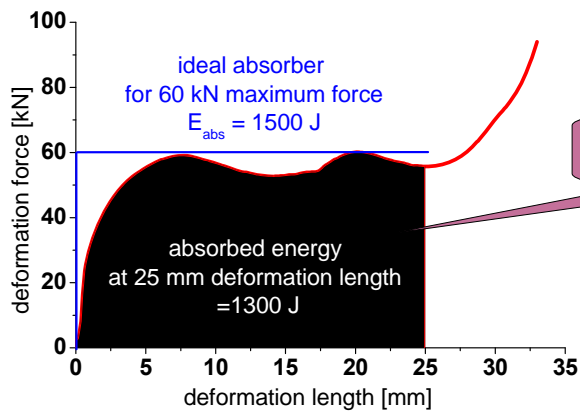


HKB

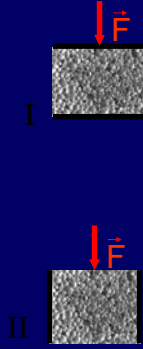
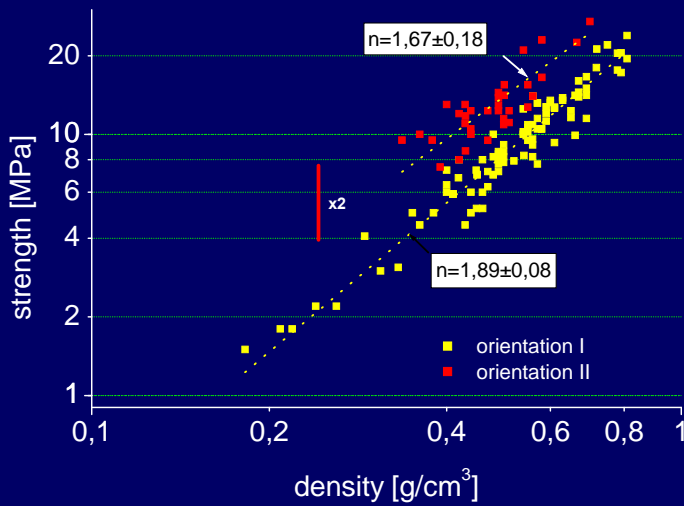


compare
 polyethylen foam (PE)
 metal foam (AlCu4)

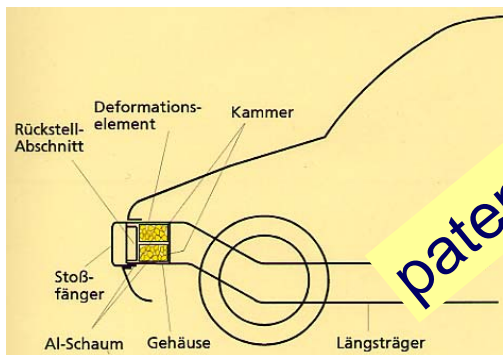
⇒ about same
 relative density
 ⇒ Al-foam stronger:
 30 ×



Compression strength as a function of density

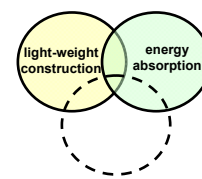


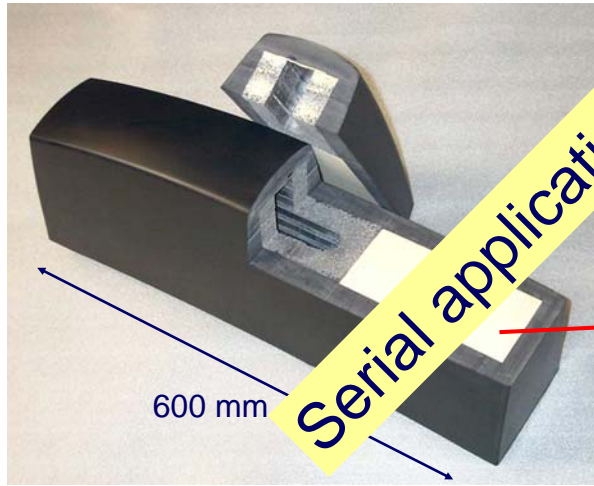
Application idea: front impact absorber



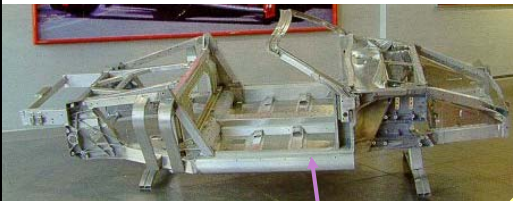
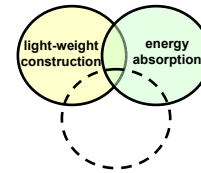
- ◆ impact energy is absorbed in crash box before longitudinal member is deformed
- ◆ exchangeable elements facilitate repair after low-velocity crashes and reduce costs

Patent-OS DE 1-95.02 307, Gerhardi & Cie.



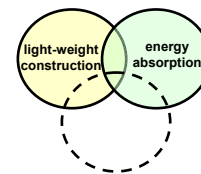
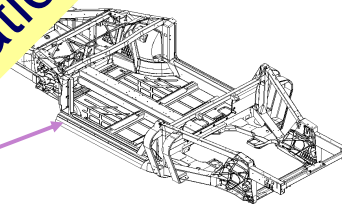


Schunk – Siemens - Hübner



Alulight

Serial application!



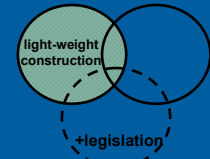
Support structure of a telescope working platform



Euro-B drivers licence

➤ less than 3500 kg total weight

- 25 m working height
- 11 m outreach

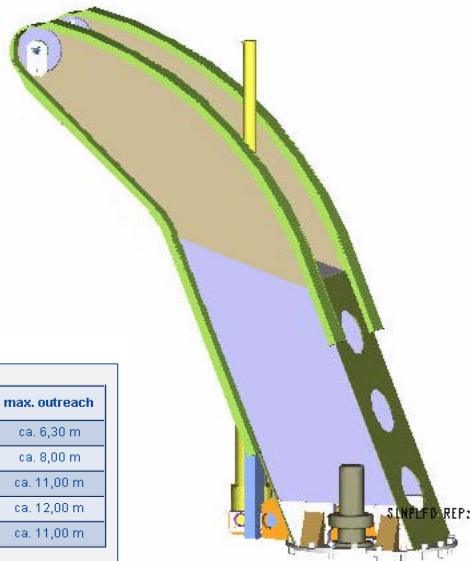


Serial application!
100 parts/year

Support structure of a telescope working platform



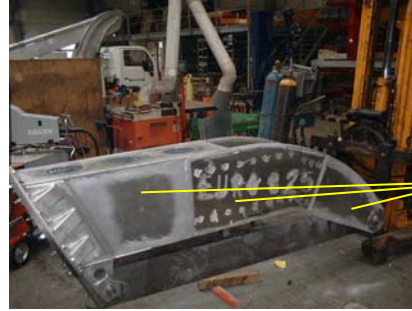
EURO B25 T
mass 110 kg
height 2441 mm
50% lighter than steel arm
production volume: 60-100 pc./yr.



The EURO B Range

| Type | height | max. working height | min. outrig. width from outrigger fast centre | max. outreach |
|--------------------|----------------|---------------------|---|---------------|
| EURO B 12 T | ≈ 2,8 t | 11,65 m | ca. 2,20 m | ca. 6,30 m |
| EURO B 14 T | ≈ 3,5 t | 13,50 m | ca. 2,20 m | ca. 8,00 m |
| EURO B 16 T | ≈ 3,5 t | 15,80 m | ca. 3,12 m | ca. 11,00 m |
| EURO B 20 T | ≈ 3,5 t | 20,00 m | ca. 3,10 m | ca. 12,00 m |
| EURO B 25 T | ≈ 3,5 t | 24,40 m | ca. 3,10 m | ca. 11,00 m |

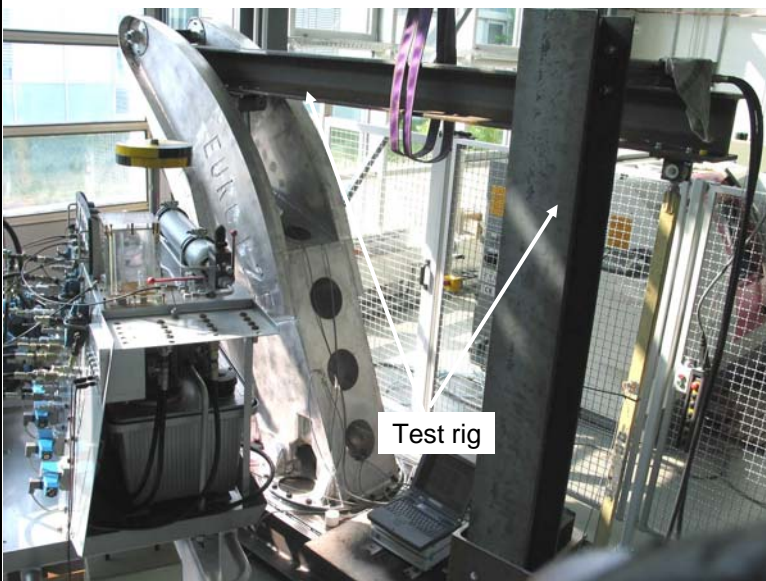
We reserve the right to make technical alterations



AFS



- 6 AFS panels, sawed to shape
- welded to each other by MIG+TIG
- AFS rim sealed with Al sheets
- inset glued into hole



Test rig

**Cyclic
multiaxial load:**

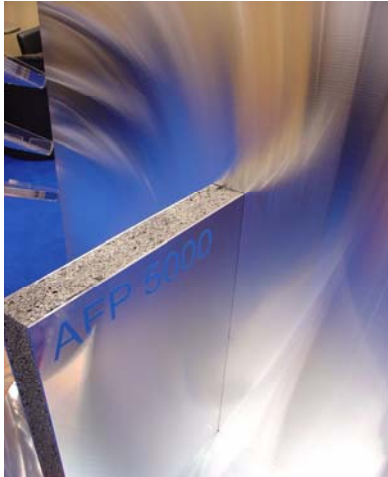
100 kN \parallel_c
14 kN \perp

Requirement:


N = 40.000

Result:

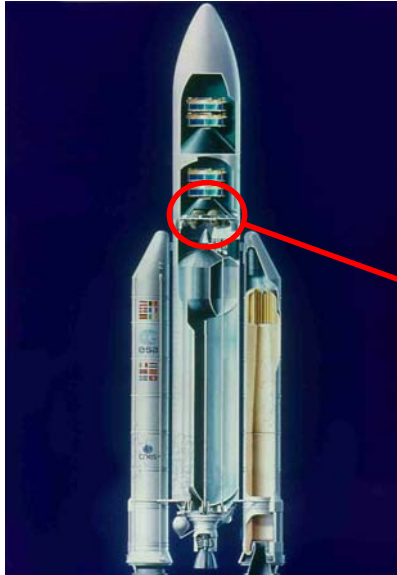
no cracks
up to
N = 100.000



- Alimex is manufacturer of high precision low residual stress aluminium plates
 - ACP series: cast plates
 - AMP series rolled plates
- New:
 - AFP: foamed AFS plate

- Properties
 - face sheets: 5083 alloy, 6 mm thick
 - foam density: 0.4 g/cm³
 - AFS: 2000 x 1000 mm; 30 to 60 mm thick
- Advantages
 - light –70 to –50% (w.r.t. Al)
 - stiffness –8%
 - cost +30%
 - weldable, application temperature range -220 to 540°C
- Applications (as given by )
 - metrology
 - platforms for milling machines and tooling
 - fire protection in trains and ships

Ariane rocket cone

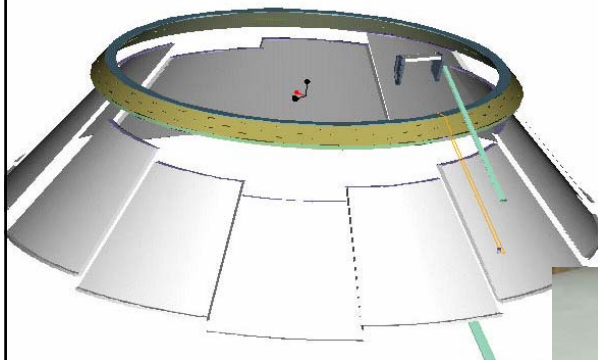


Existing part:
aluminium honeycomb + Al ring

Too expensive!



Ariane Rocket Cone 3936 AFS replacement

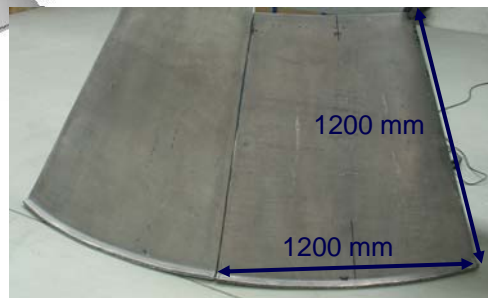


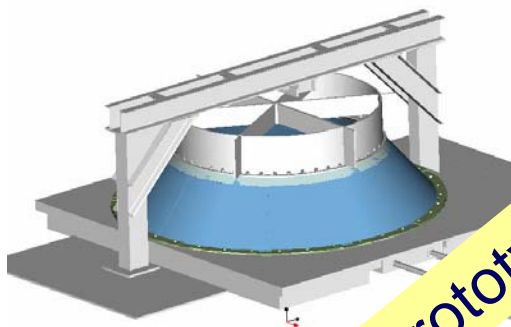
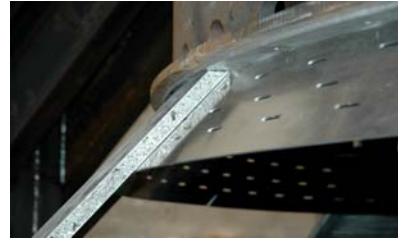
Dimensions

- Upper diameter 2624 mm
- Lower diameter 3936 mm
- Total weight: 180 kg
- 12 Segments 1200x1200x25 mm
- face sheet s 1.3 mm thick

Technology:

- 3D foamed AFS 6060 + AlCu6Cu6
- TIG welded, manually

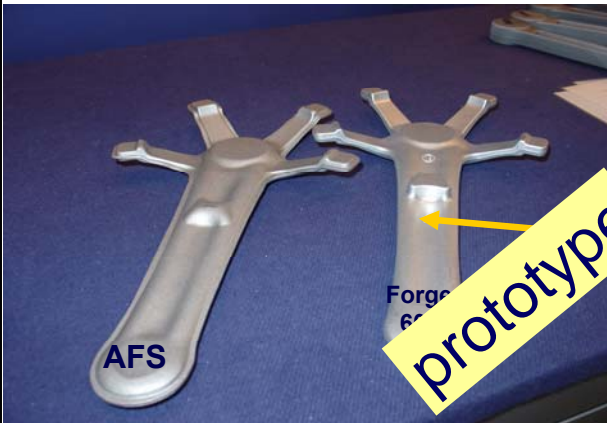




prototype

Test Load up to 10 t normal to cone
10 t in plane of the upper ring
0.03 mm elastic deformation (15% too high)
Status: optimisation necessary





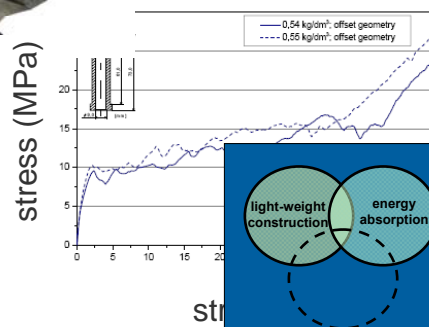
- Conventional Al crank arm: **313 g**,
 ➢ 7g lighter than 2nd lightest product
- AFS crank arm: **222 g** = -30%

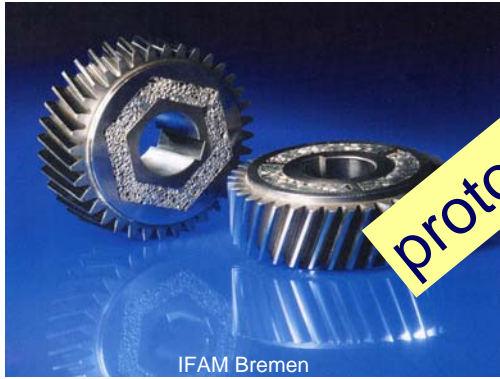
direct substitution, design adapted to AFS will further improve



Serial production of relevant part in Audi Q7 “pike crash test”

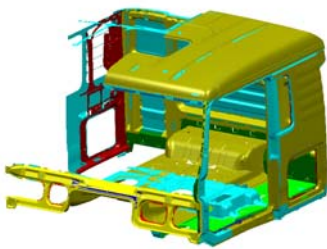
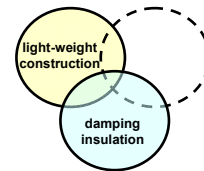
Limits forces to 1.5 kN at 50% deformation (of 73 mm)





prototype

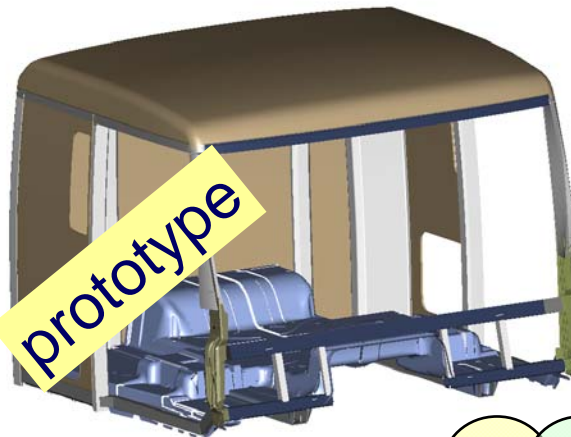
Gear-wheel with an anti-vibration layer of aluminium foam



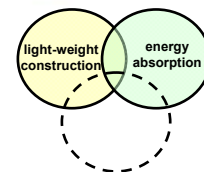
Steel-based
total mass
294 kg

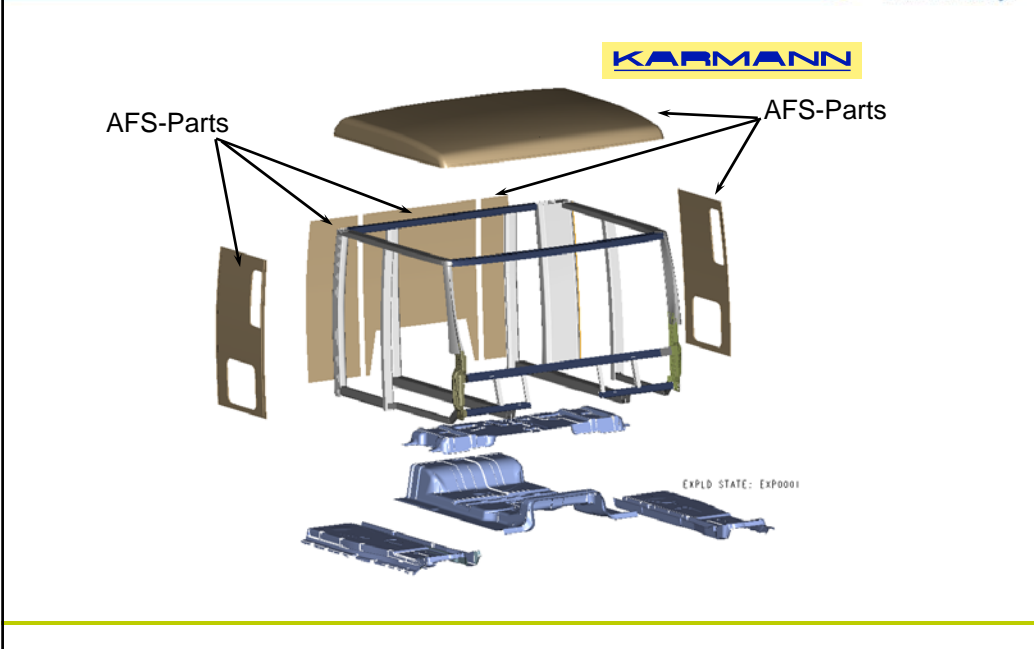
- weight reduction > 30%
- increase in stiffness > 15 %
- better crash behaviour

prototype

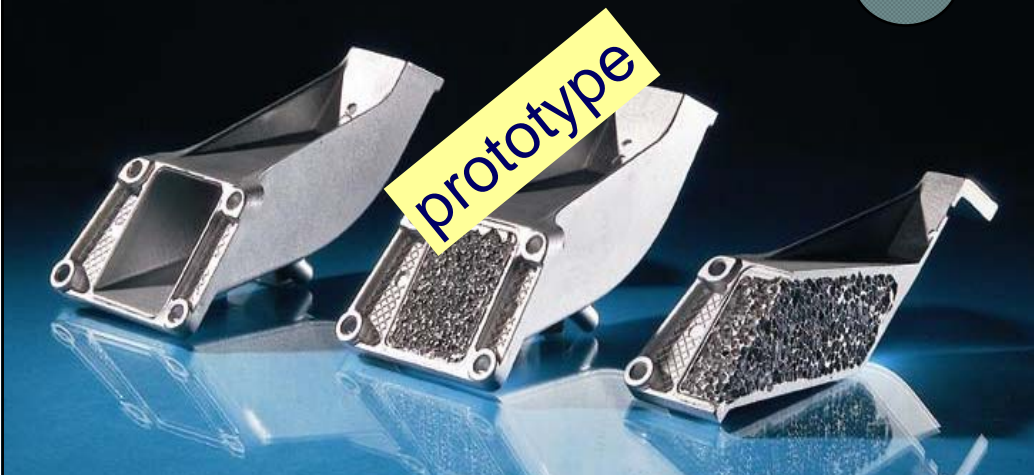
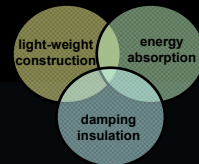


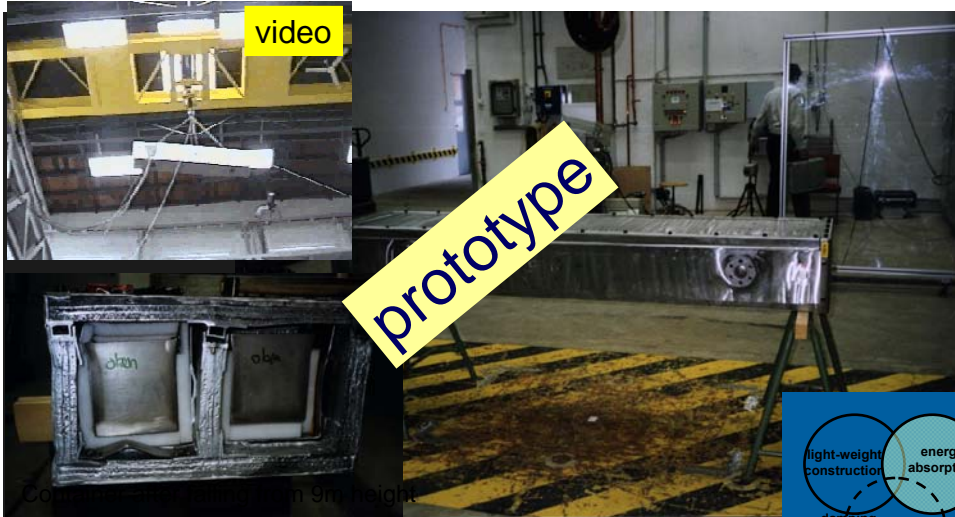
AFS-based
total mass
220 kg





Engine bracket for BMW

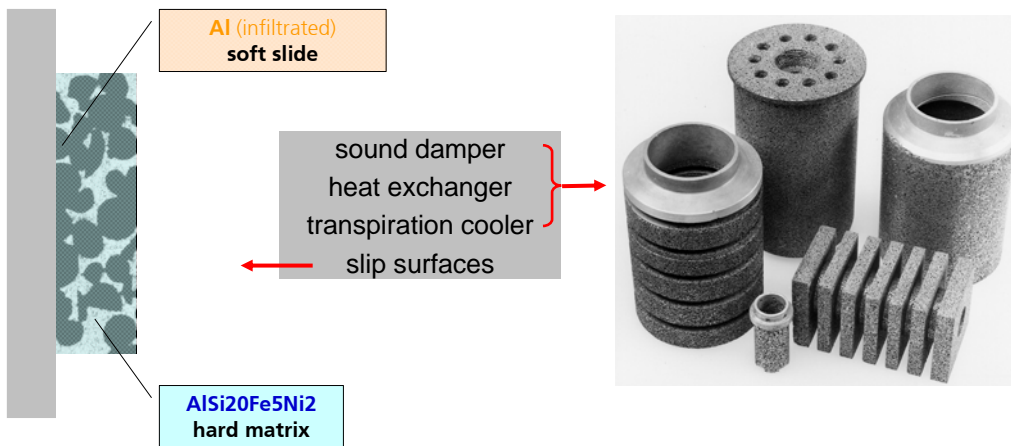
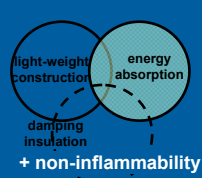




video

prototype

KARMANN



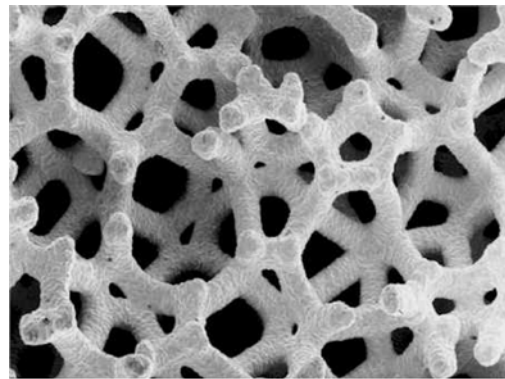
AI (infiltrated)
soft slide

sound damper
heat exchanger
transpiration cooler
slip surfaces

AISI20Fe5Ni2
hard matrix

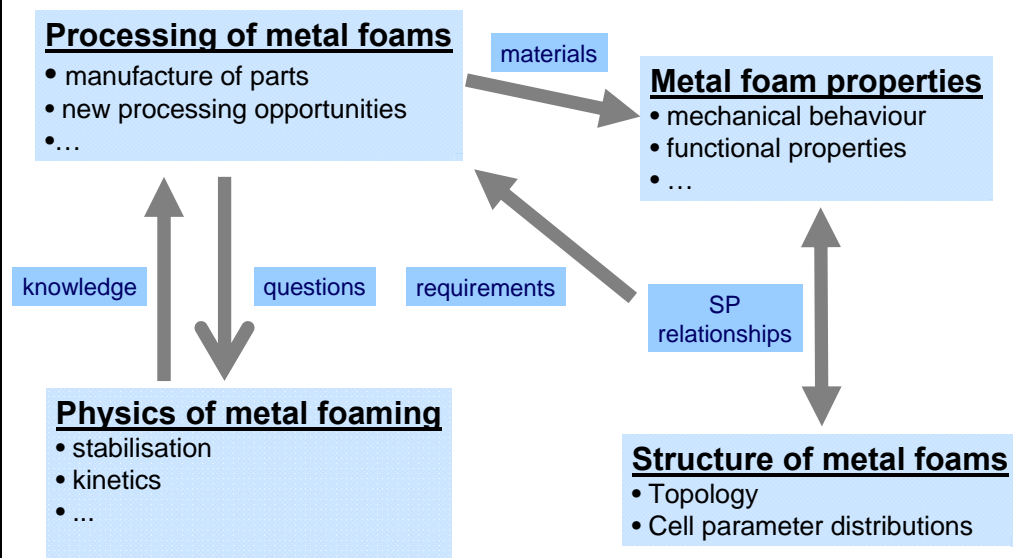
Applications:

- catalyst support
- oxidation resistant structures, filtration
- bio-compatible implant structures

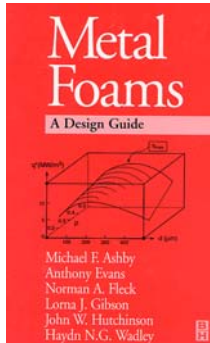


cell Size: 0.2-2.5mm

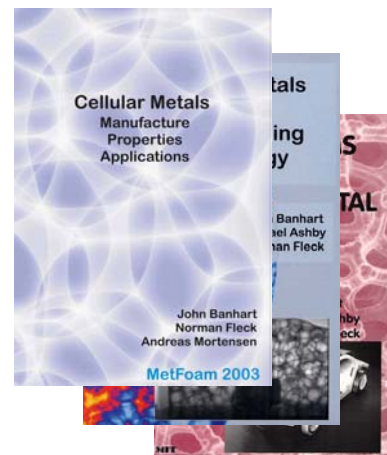
ρ/ρ_s : 2-10%



What to read



M.F. Ashby, A.G. Evans, N.A. Fleck,
L.J. Gibson, J.W. Hutchinson, H.N.G. Wadley
Metal Foams - A Design Guide
Butterworth-Heinemann (2000)



J. Banhart, M.F. Ashby, N.A. Fleck: **MetFoam1999**
J. Banhart, M.F. Ashby, N.A. Fleck: **MetFoam2001**
J. Banhart, N.A. Fleck, A. Mortensen: **MetFoam2003**
H. Nakajima, N. Katetake: **Metfoam2005**
L.-P. Lefebvre, J. Banhart, D. Dunand: **Metfoam2007**

Where to go in the internet and in the real world?

<http://www.metalfoam.net>

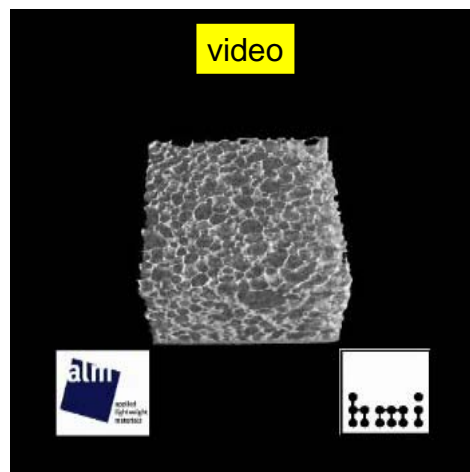
6th International Conference
MetFoam2009
Bratislava, 2.-4.9.2009

banhart@helmholtz-berlin.de

Work at the department “Materials”

The team comprises

- 4 working groups:
 - metal foams, microstructure, imaging, scattering
- About 25 researchers
 - 1 Professor, 2 Lecturers, 6 Senior scientists, 4 Postdocs, 8 PhD students, 4 Diploma/MSc students + Students
 - + 5 Technicians, 1 Secretary
- We offer open positions on
http://www.hmi.de/bereiche/SF/SF3/job_opportunities/index_en.htm



Thank you!