Syntactic Metal Foams

ENGR-220-88

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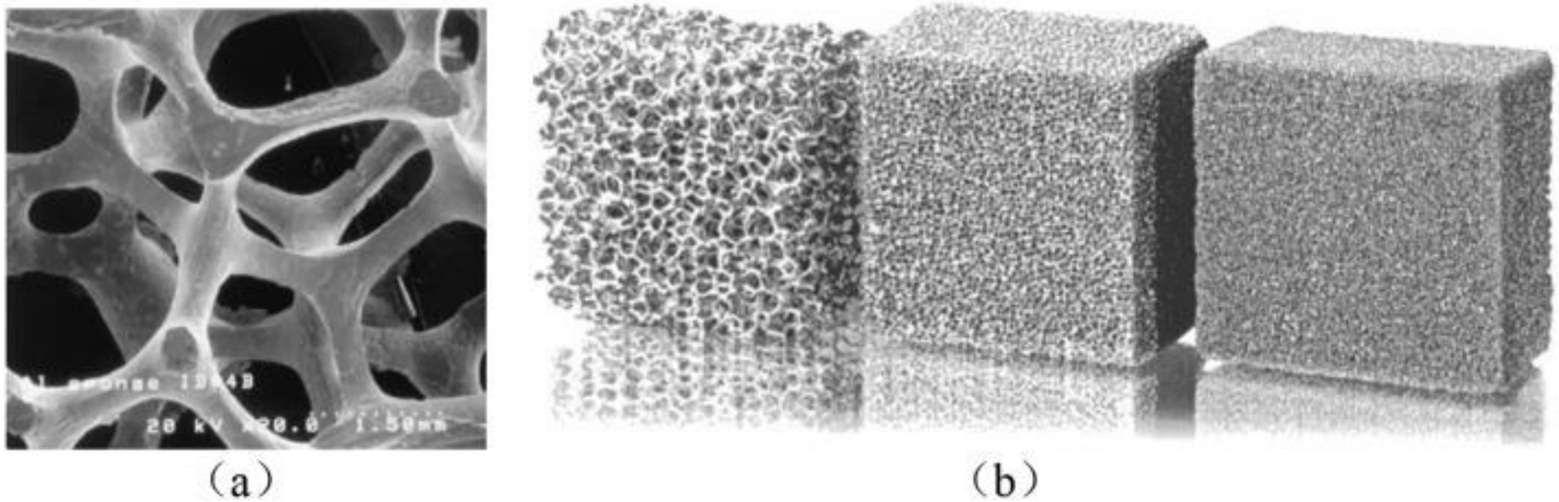
Definition

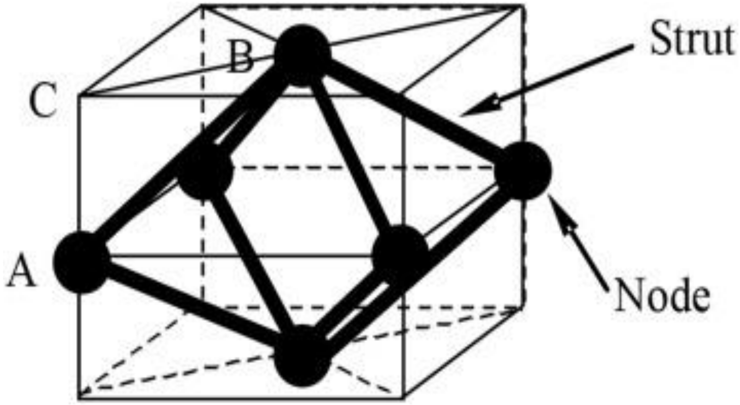
Syntactic Metal Foams (MSFs) - a material whose foam structure is provided by non-metallic spheres with a hollow or porous structure mixed into the base metal, therefore they can also be considered as a metal-matrix composite in which the primary role of the reinforcing material is to reduce density [6].



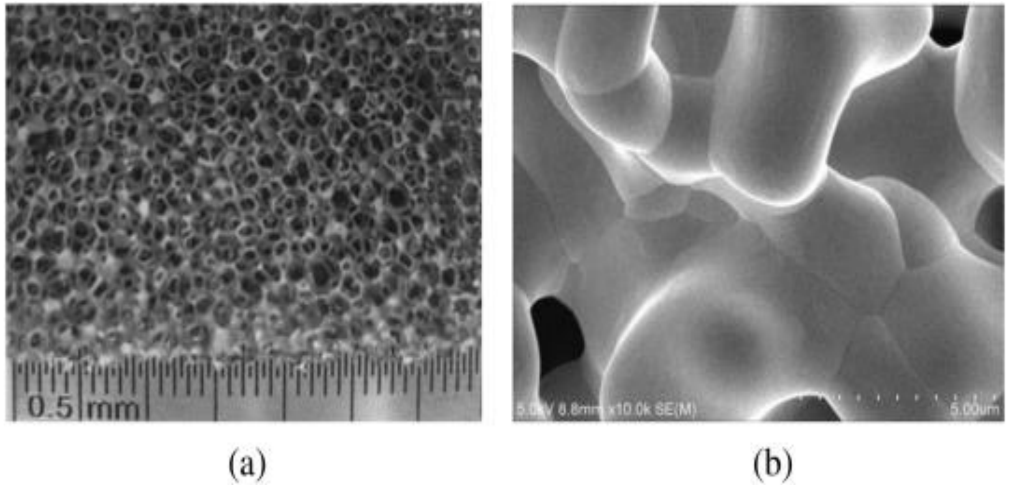
(a) porous structure of syntactic metal foams (b) product blocks of syntactic metal foams [9].

Definition (cont.)

- Considered as metal composites, made up of two or more materials
- Octahedral reticular atomic structure
- Octahedral pore-units connected by strong grain bonding



Octahedral pore unit in reticular porous materials [9].



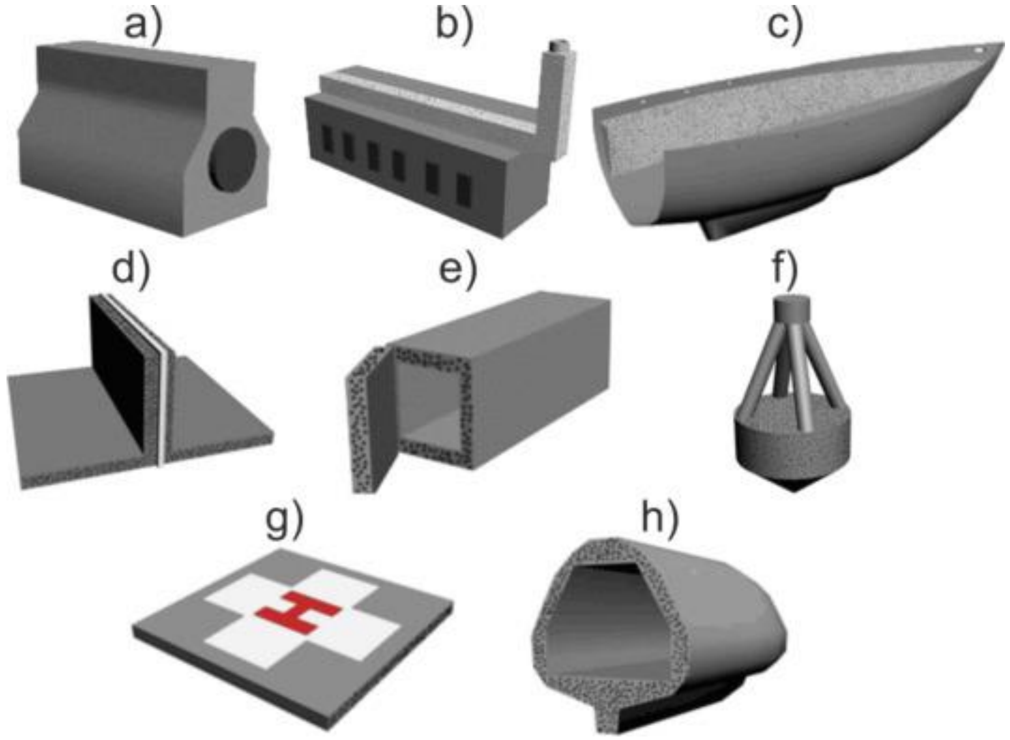
Example of reticular tungsten foam: (a) macroscopic morphology; (b) grain bonding state [9].

Introduction

- Syntactic metal foams are the future of mechanical/structural design
- MSFs possess multiple advantageous physical and mechanical properties
- Useful for various engineering applications

Applications

- Used in energy engineering, machinery, construction, electrochemistry, bioengineering, environmental protection, transportation, aviation and aerospace [9].
- Examples: lightweight structures, sandwich cores, mechanical damping, vibration control, energy management, artificial wood, thermal management, biocompatible inserts, filters, electrical screening, and buoyancy [2].

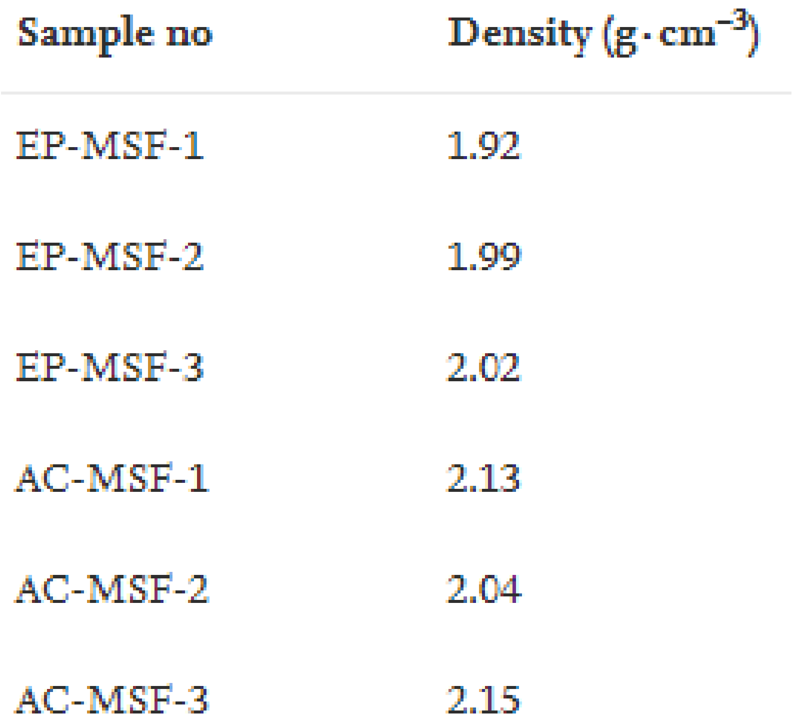


Examples of marine structures, exhaust and generator systems, fire-resistant structures, etc. [5].

Physical Properties

Density

- Lightweight because of high porosity (empty air-filled spaces)
- Density ranges between 1.90-2.20 g·cm^{-3}



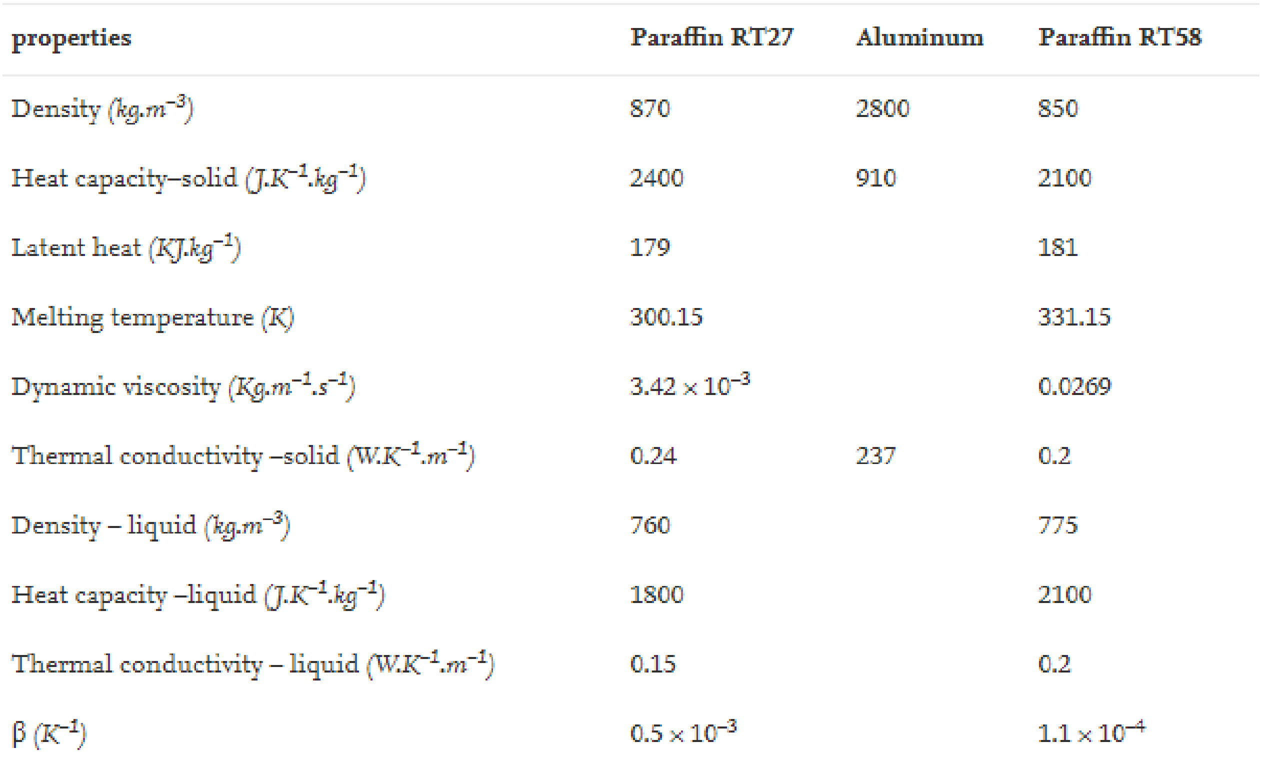
Sample no	Density (g · cm^{-3})
EP-MSF-1	1.92
EP-MSF-2	1.99
EP-MSF-3	2.02
AC-MSF-1	2.13
AC-MSF-2	2.04
AC-MSF-3	2.15

Densities of the uniform syntactic metal foam samples [10].

Physical Properties (cont.)

Thermal Conductivity

- Low thermal conductivity
- Embedded phase change materials (PCMs) provide improved thermal conductivity



properties	Paraffin RT27	Aluminum	Paraffin RT58
Density ($kg.m^{-3}$)	870	2800	850
Heat capacity–solid ($J.K^{-1}.kg^{-1}$)	2400	910	2100
Latent heat ($KJ.kg^{-1}$)	179		181
Melting temperature (K)	300.15		331.15
Dynamic viscosity ($Kg.m^{-1}.s^{-1}$)	3.42×10^{-3}		0.0269
Thermal conductivity –solid ($W.K^{-1}.m^{-1}$)	0.24	237	0.2
Density – liquid ($kg.m^{-3}$)	760		775
Heat capacity –liquid ($J.K^{-1}.kg^{-1}$)	1800		2100
Thermal conductivity – liquid ($W.K^{-1}.m^{-1}$)	0.15		0.2
β (K^{-1})	0.5×10^{-3}		1.1×10^{-4}

Thermophysical properties of paraffin RT27, RT58 and aluminum foam. [4].

Physical Properties (cont.)

Electrical Conductivity

- Low electrical conductivity
- Lower than many other materials
- Provide electromagnetic shielding

Superconductivity

- MSFs are superconductors
- Delivers electricity with little resistance

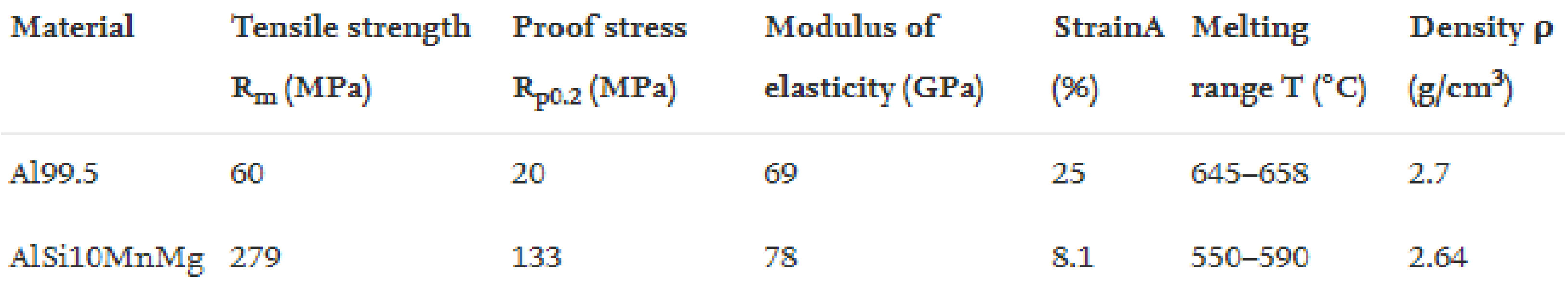
Physical Properties (cont.)

Specific Heat

- Cools quicker due to high porosity in structure
- Higher specific heat than other base metals

Melting Range

- Higher than regular metals
- Around 500°C - 650°C melting point



Material	Tensile strength R_m (MPa)	Proof stress $R_{p0.2}$ (MPa)	Modulus of elasticity (GPa)	StrainA (%)	Melting range T (°C)	Density ρ (g/cm^3)
Al99.5	60	20	69	25	645–658	2.7
AlSi10MnMg	279	133	78	8.1	550–590	2.64

Properties of different metal samples that are used in metal foams, includes melting range. [6].

Physical Properties (cont.)

Thermal Behavior

- Little to no deformation under regular temperatures
- If melted, can jeopardize porous structure

Magnetic Properties

- Magnetic because of metals within MSFs

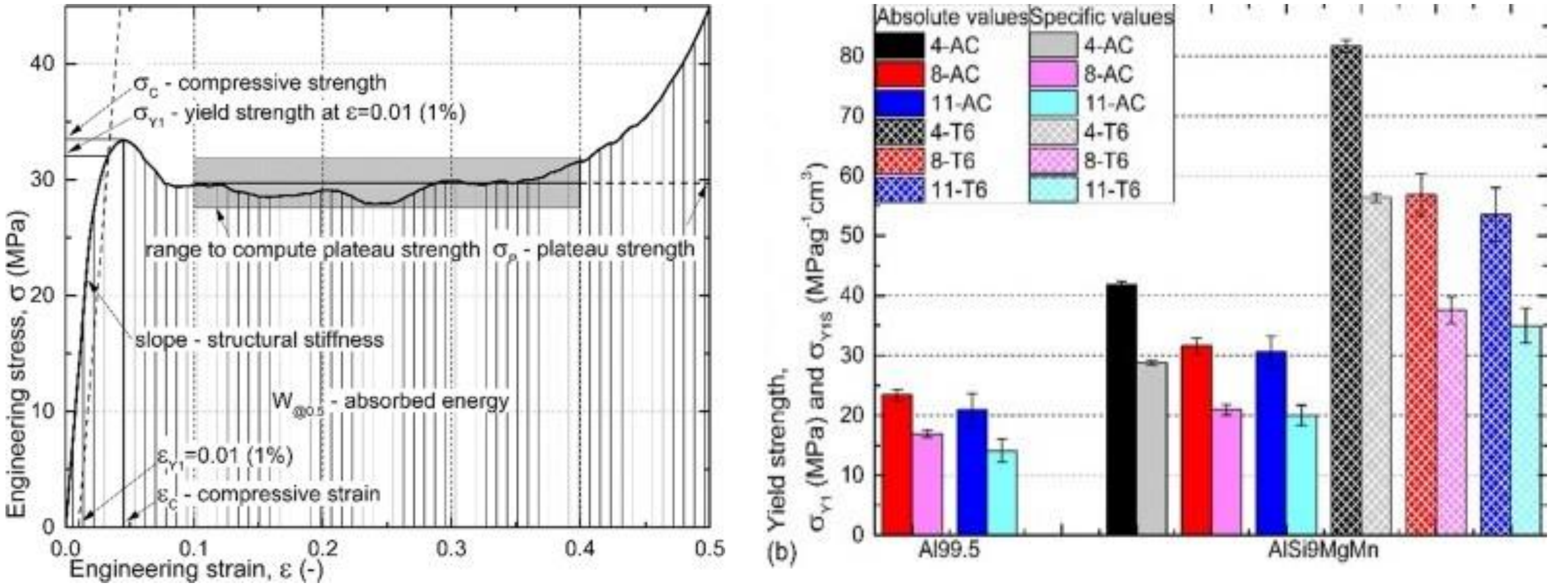
Phase Transformations

- Can be in a solid or liquid state
- When in a liquid state, pores are destroyed

Mechanical Properties

Yield Strength

- Possesses very high yield strength
- Can undergo about 80% compression of its own volume

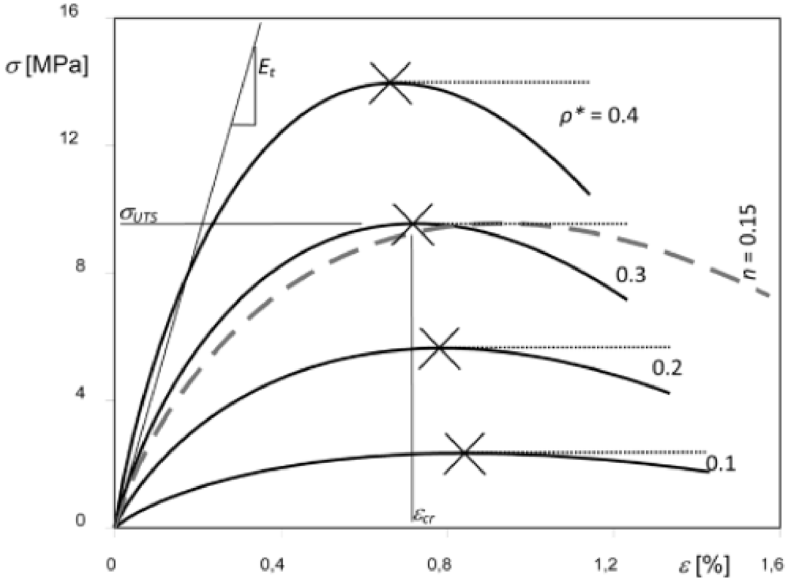


(Left) Generalized compressive engineering stress – engineering strain curve of syntactic metal foams. (Right) Yield strengths of multiple material samples [11].

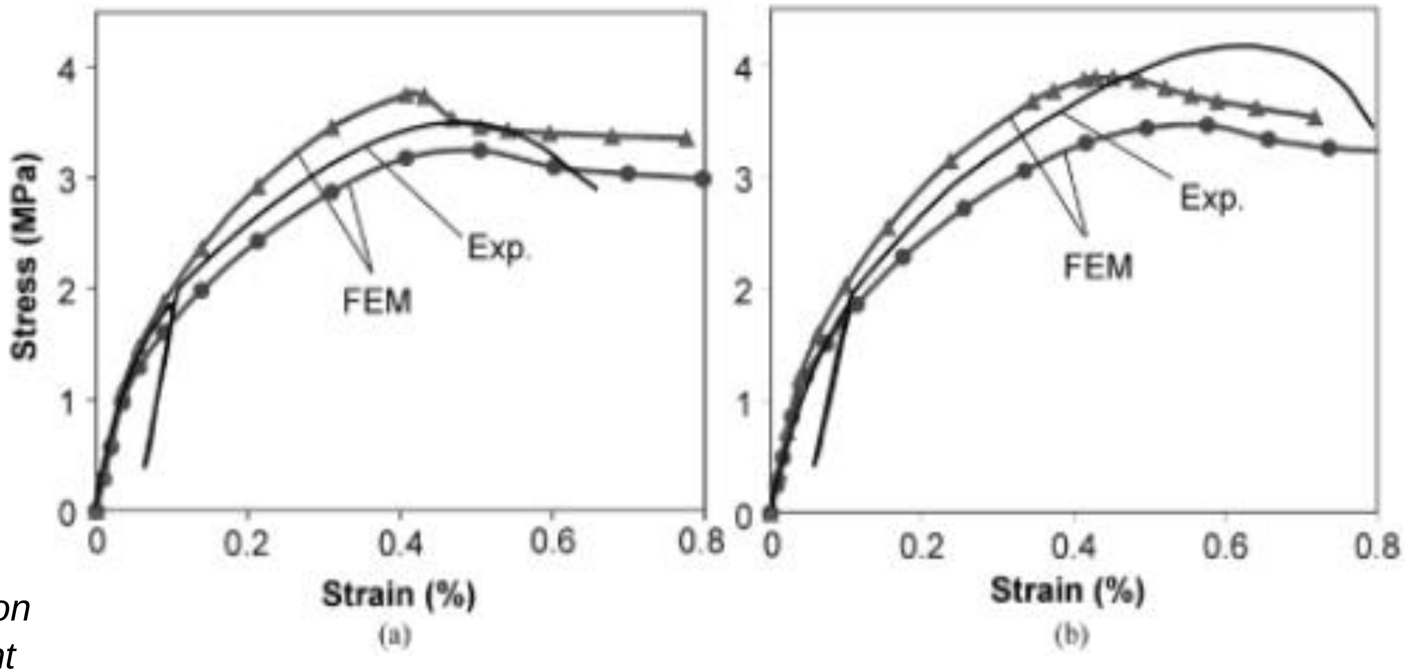
Mechanical Properties

Tensile Strength

- Has good tensile strength, not as impressive as yield strength



Simulated flow curves used for AlSi10 material, plastic deformation represented by dotted-lines, ultimate tensile strengths at different strain-hardening exponents represented by solid lines [3].

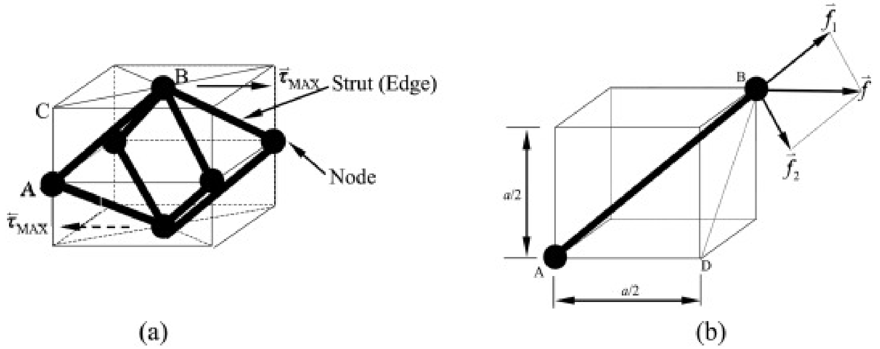


Experimented tensile test results compared with simulated stress-strain curves, (a) transverse sample, (b) longitudinal sample [3].

Mechanical Properties (cont.)

Shear Strength

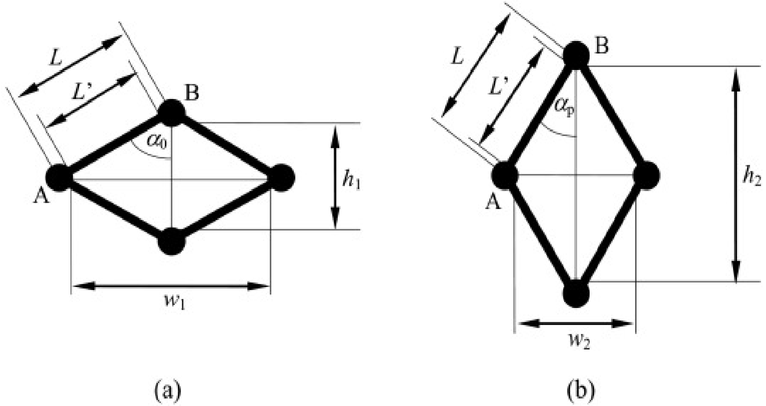
- Has good shear strength



Pore unit of the porous body under shearing loads, (a) the octahedral unit; (b) the pore strut [9].

Elongation

- Higher porosity means higher elongation rate



Model for the tensile deformation of octahedral pore unit: (a) before tension; (b) after tension when the stress in the pore-strut arrives at the proportional limit of the corresponding dense material species. [9].

Mechanical Properties (cont.)

Young’s Modulus

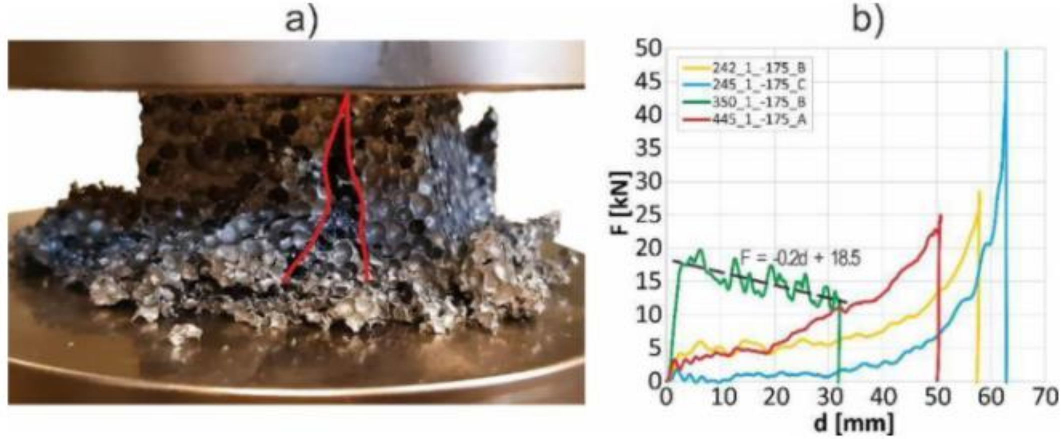
- Relates to elongation
- Porous bodies have a high Young’s Modulus

Ductility

- Fractures when high force is loaded onto material

Impact Strength

- Can withstand lots of impact
- Can fracture under high amounts of applied force



Brittle fracturing of 350-type metal foam, (a) foam fracture during compression, (b) graph F = f(d) [5].

Mechanical Properties (cont.)

Fatigue Resistance

- Flexible and compressible
- Faces little fatigue

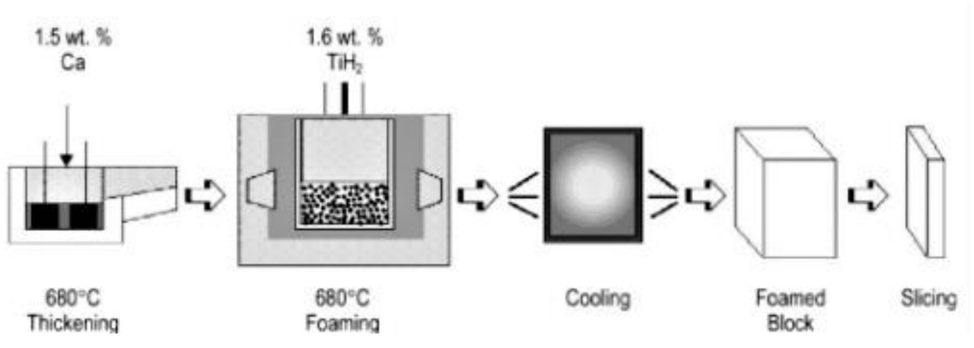
Failure Analysis and Prevention

- If one pore-strut fails, all of them fail
- Tearing and fracturing can occur
- Lower porosity can strengthen foam
- Thicker pore-strut bonding

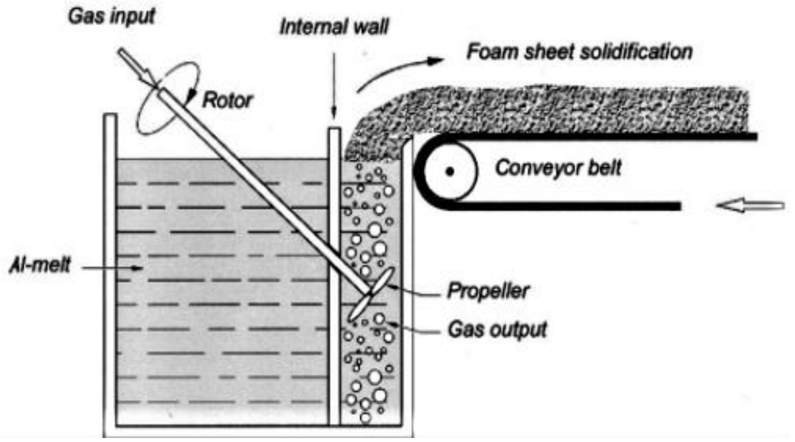
Manufacturing Process

- There are many manufacturing methods, and various processes within these methods
- These production methods make metal foams from metallic melts, solid metals, or electroplating

Making Metal Foams from Metallic Melts:



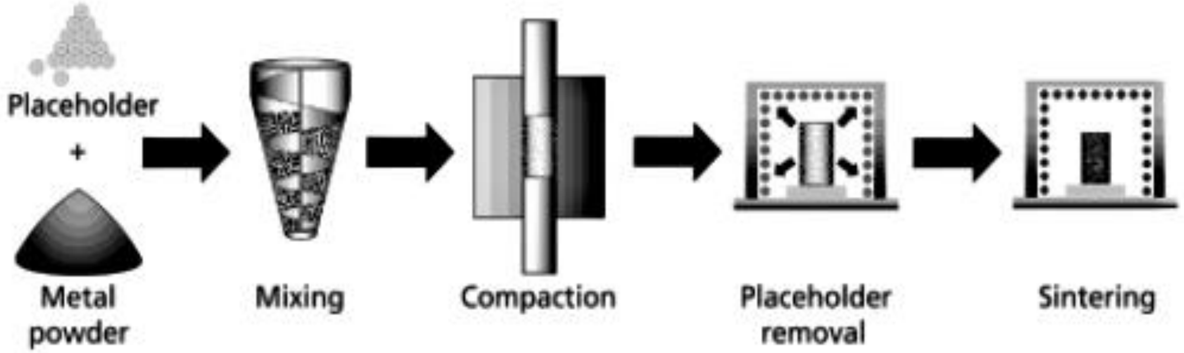
Direct foaming of melts with blowing agents (ALPORAS process) [3].



Direct foaming of melts by gas injection [3].

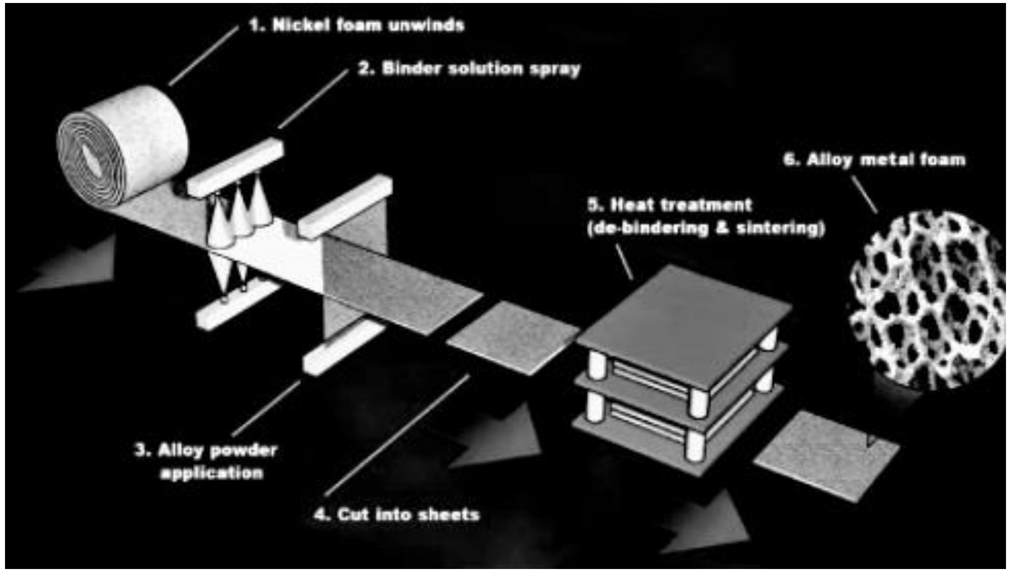
Manufacturing Process (cont.)

Making Metal Foams from Solid Metals:



Process scheme of the p/m space-holder methods [3].

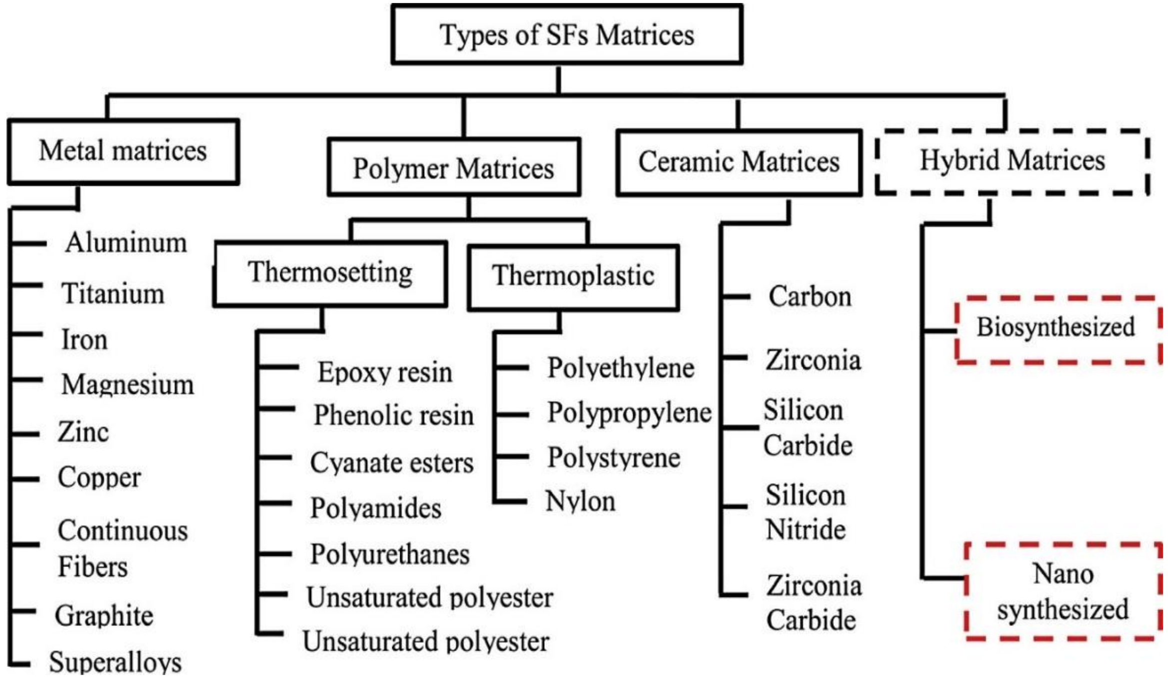
Making Metal Foams from Electroplating:



Production scheme for high temperature alloy foams [3].

Materials and Environment

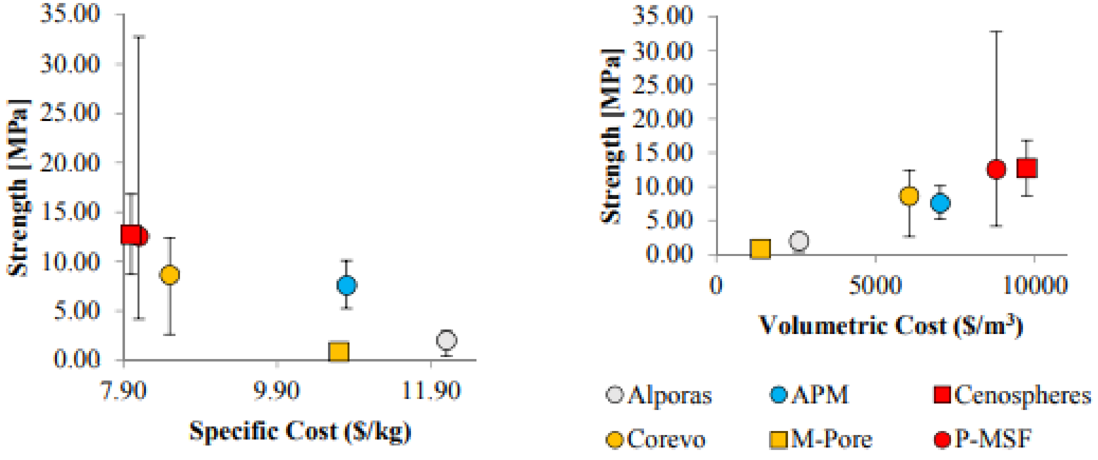
- Most common types of metals used in MSFs are aluminum, titanium, iron, copper, and more.
- Porous foams can be made in different types



Syntactic foam matrices [1].

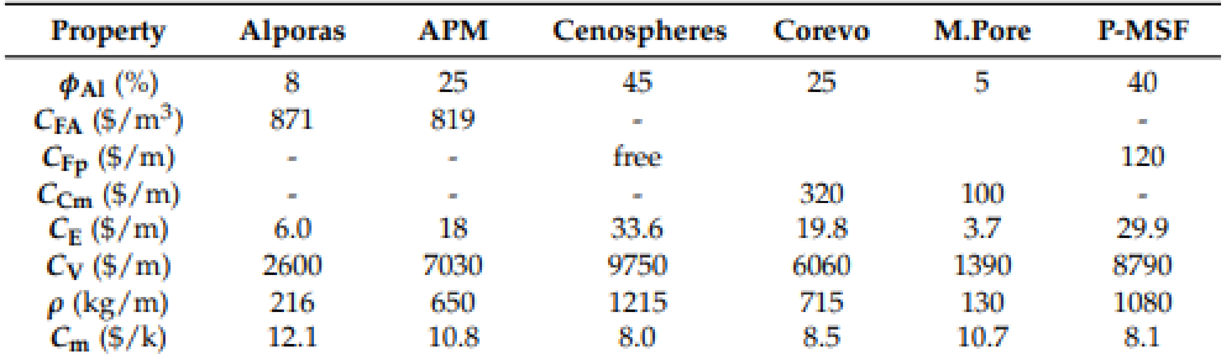
Cost Analysis

- Specific cost is lower for MSFs compared to other materials, in relation to strength
- Volumetric cost is higher for MSFs compared to other materials, in relation to strength



(a) (b)

Material strength plotted versus (a) specific cost and (b) volumetric cost for selected types of cellular metals [7].



Property	Alporas	APM	Cenospheres	Corevo	M.Pore	P-MSF
ϕ_{Al} (%)	8	25	45	25	5	40
C_{FA} ($\$/m^3$)	871	819	-			-
C_{Fp} ($\$/m$)	-	-	free			120
C_{Cm} ($\$/m$)	-	-	-	320	100	-
C_E ($\$/m$)	6.0	18	33.6	19.8	3.7	29.9
C_V ($\$/m$)	2600	7030	9750	6060	1390	8790
ρ (kg/m)	216	650	1215	715	130	1080
C_m ($\$/k$)	12.1	10.8	8.0	8.5	10.7	8.1

Overview of cost figures for selected types of cellular metals and their base metals [7].

Conclusion

- Syntactic metal foams have advantageous physical and mechanical properties
- MSFs can be made in many ways with various metals
- Very useful for various engineering applications

Thank you for Listening!

I will be taking any questions at this time.

References

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