

Materials Processing for Light Metals with Meso-scale Structures; Porous Metals



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Outline

- **Introduction:**
 - Porous structures in nature
 - Man-made porous metals
- **Conventional processing for making porous aluminum**
 - Precursor method, Spacer (Space holder) method
- **Processing for high-melting- temperature porous aluminides**
 - Reactive precursor method
 - Variety of porous structure
- **Summary**

Introduction... porous structures in nature

When a modern man builds large load-bearing structures, *he uses dense solids*; steel, concrete, glass. When nature does the same, *she generally uses porous materials*; wood, bone, coral. *There must be good reasons for it.*

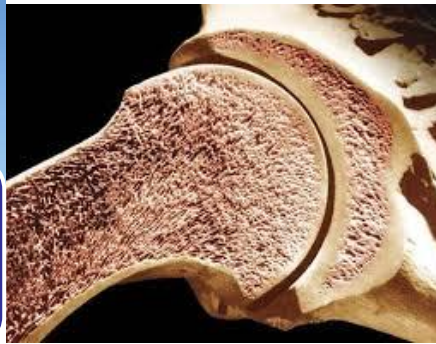
Prof. M.F.Ashby, University of Cambridge

The thigh bone

Designed for both maximizing bending and buckling strength and minimizing weight.

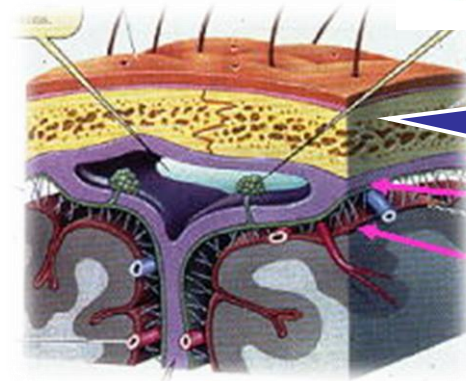


Aligned along the loading direction



The skull

Designed for absorbing impact energy to protect your brain.



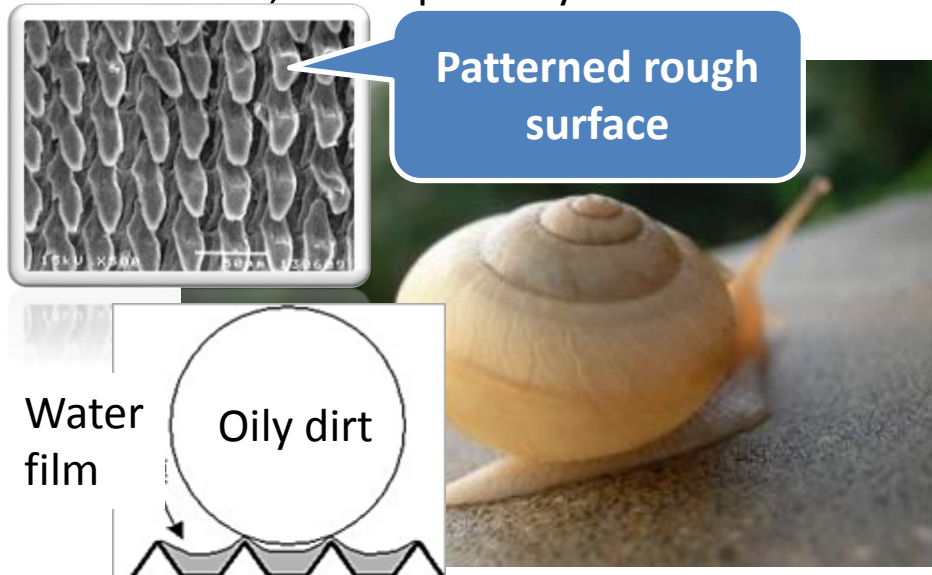
Sandwich structure.

Introduction... porous structures in nature

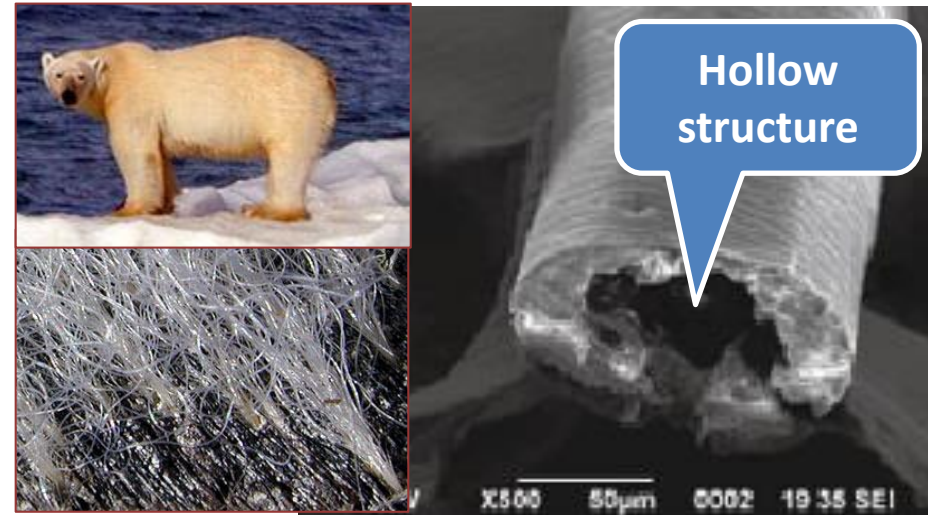
When a modern man builds large load-bearing structures, *he uses dense solids*; steel, concrete, glass. When nature does the same, *she generally uses porous materials*; wood, bone, coral. *There must be good reasons for it.*

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The moisture in the air condenses on **snail shell** surface, and repels oily dirt.

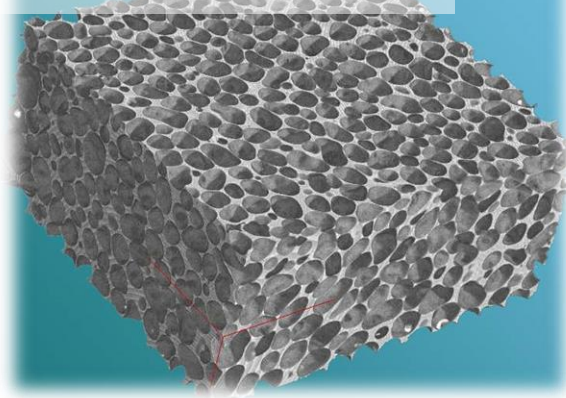


The **hollow fur** of the polar bear provides excellent **thermal insulation** from the cold.



Man-made porous Al: Impact energy absorber

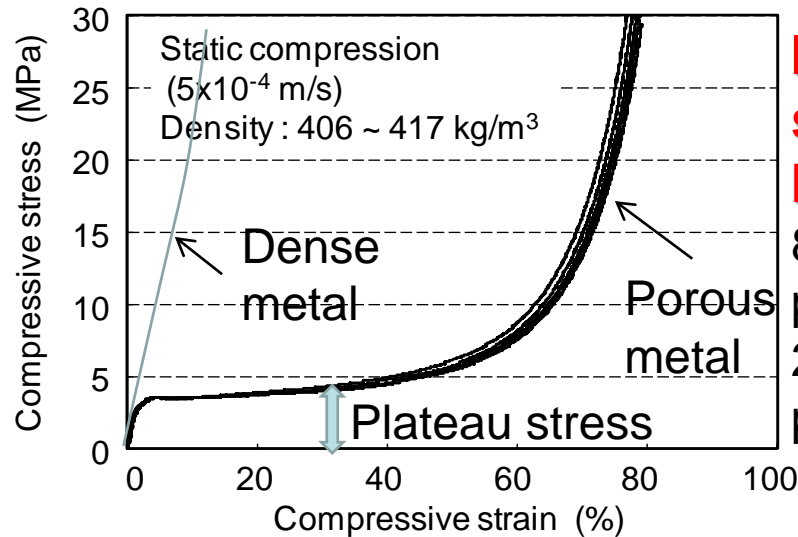
Closed cell structure



Energy absorber



Drop weight test
(High-speed camera)



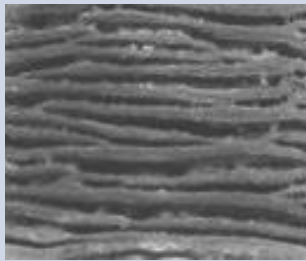
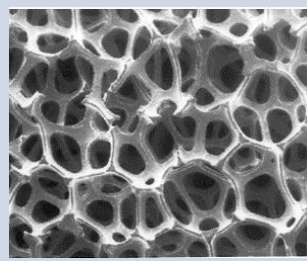
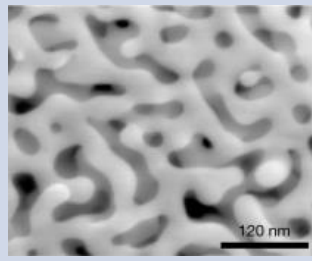


Ideal plateau stress for bumper
8~10 MPa (for passenger safety)
2~3 MPa (for pedestrian safety)

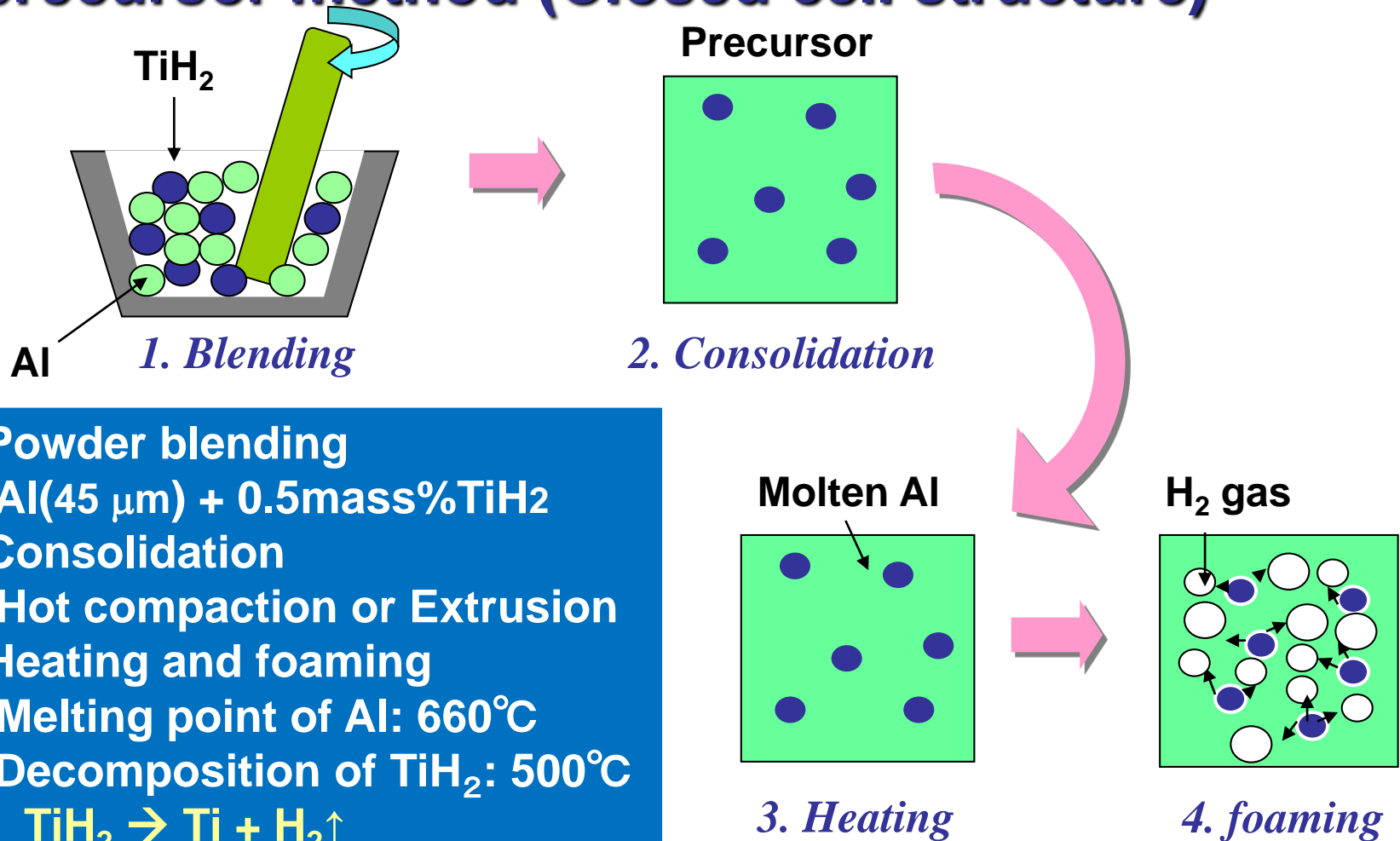
Large deformation at a constant stress level is an ideal property for a impact energy absorber.

Man-made porous metals and their functions

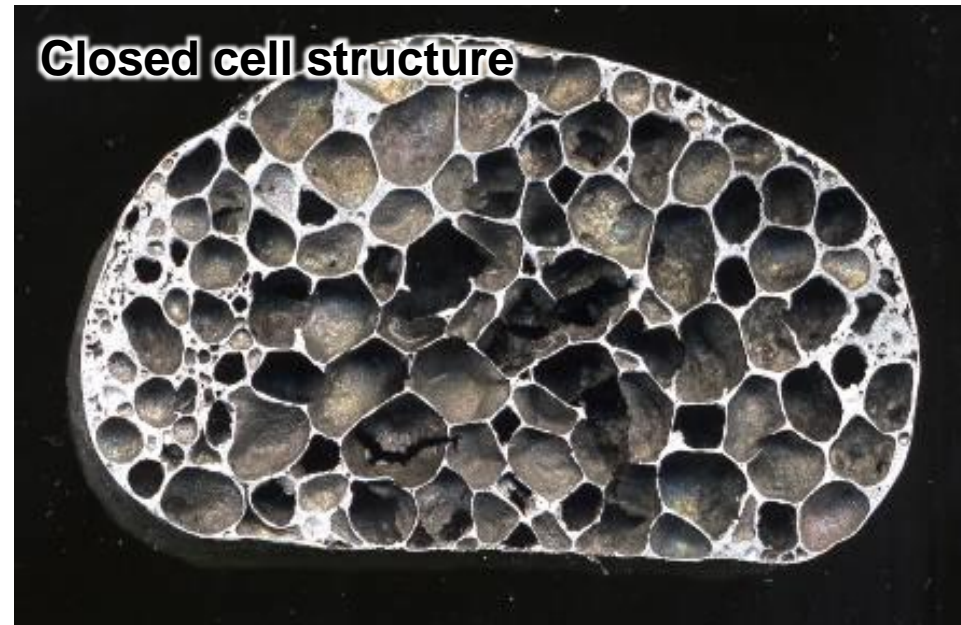
The porous metal is a kind of nature inspired materials, and can be classified according to shape and size of the pores.

Category	Closed cell (Equi-axed)	Lotus cell (uni-directional)	Flat cell (Lamellar)	Open cell (Sponge)	Open cell (Nano)
Cross-section					
Functions	<i>High damping capacity, Impact energy absorption, High specific modulus</i>	<i>Fluid Permeability, High specific modulus, High damping capacity</i>	<i>Low thermal conductivity</i>	<i>High liquid absorbency, Fluid permeability, Capillary force, Acoustic absorption</i>	<i>Catalytic property, High liquid absorbency, Large surface area</i>

Fabrication route of porous aluminum by precursor method (Closed cell structure)



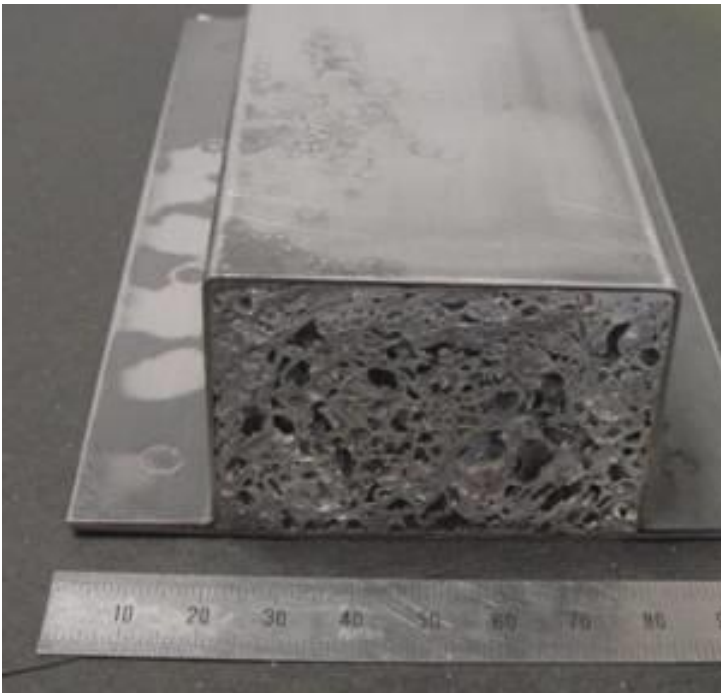
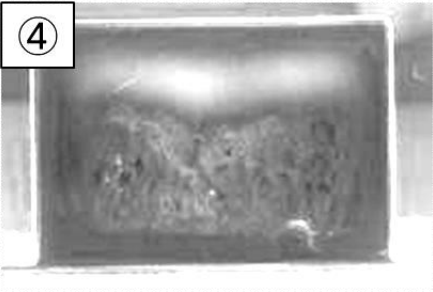
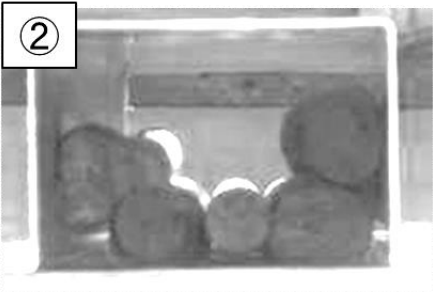
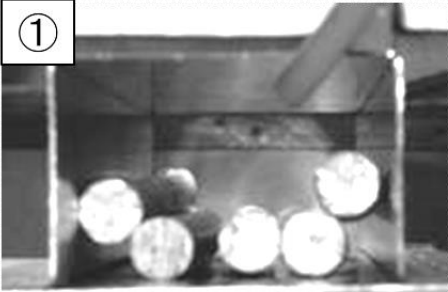
Fabrication route of porous aluminum by precursor method (Closed cell structure)



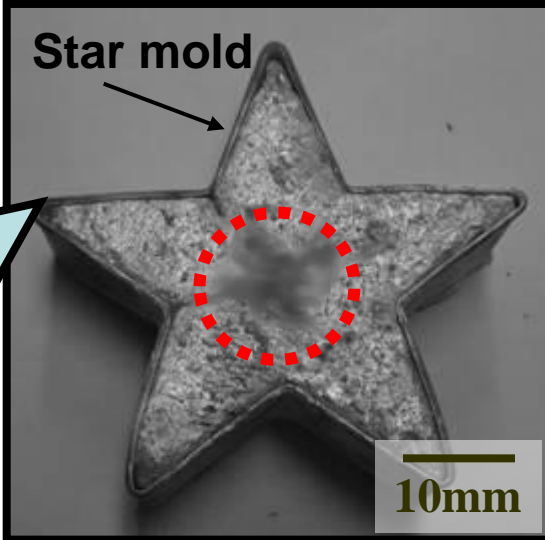
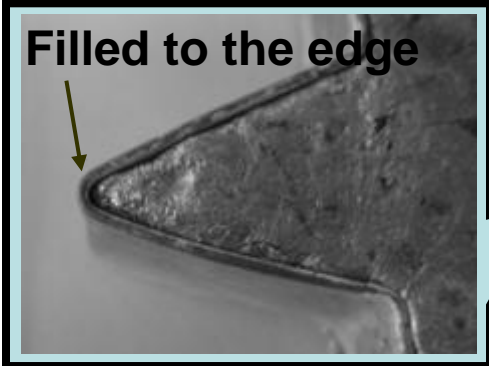
20 mm

Blowing behavior of plate-shape precursor heated by an induction coil

Foamed in hollow components

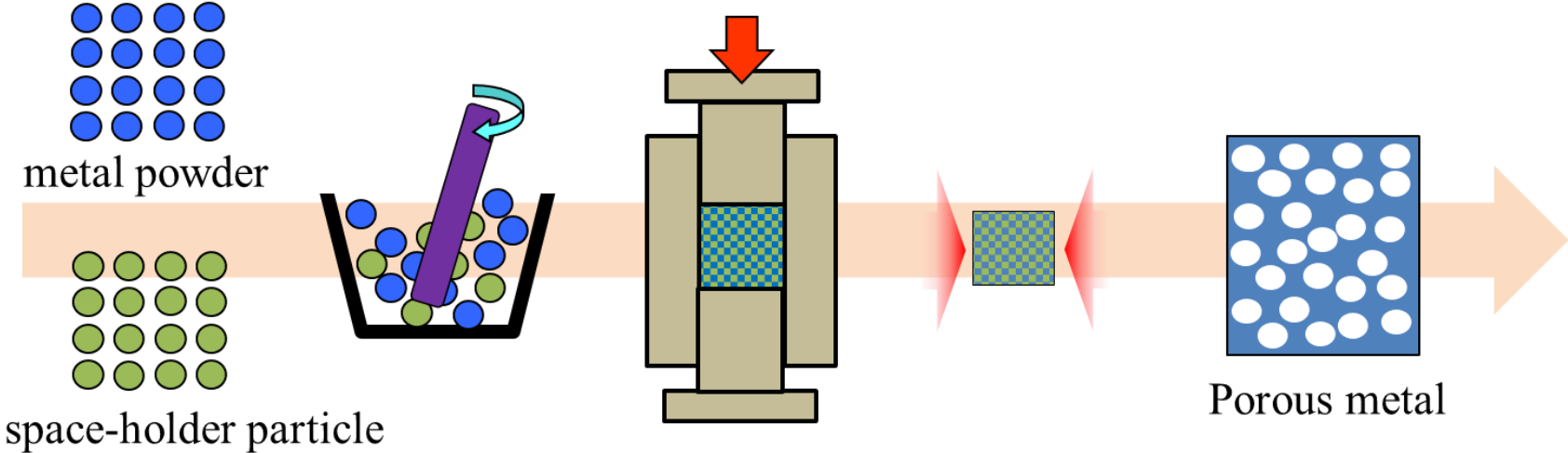
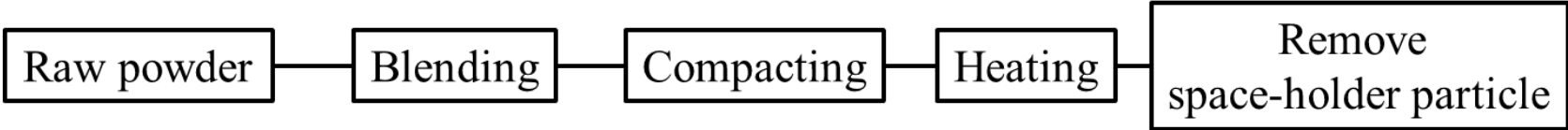


Porous Al filled in a hollow tube

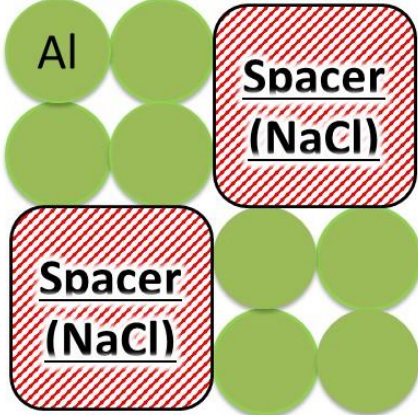


Foamed in a star-shape mold

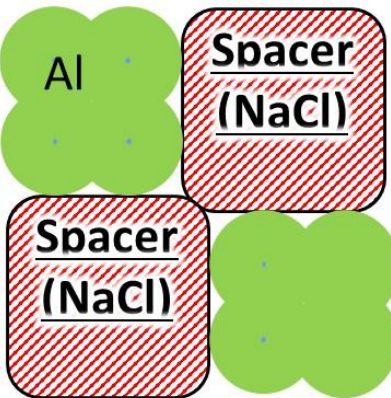
Fabrication route of porous aluminum by spaceholder method (open cell structure)



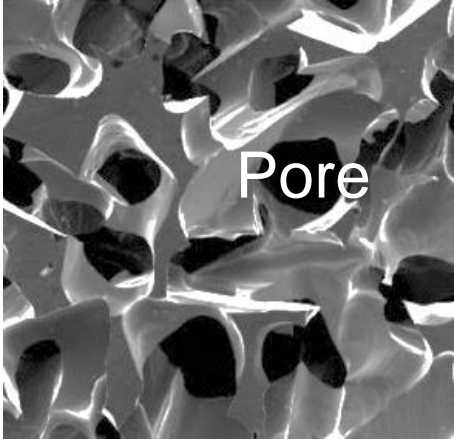
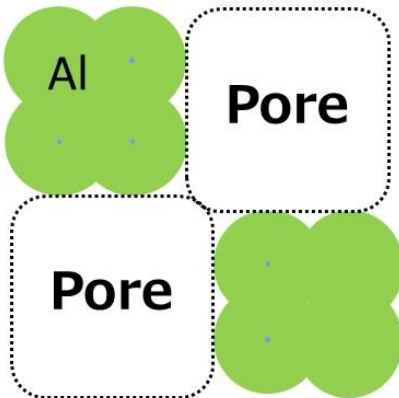
Powder blend



Sintering



Leaching in water



Limitations of conventional process

Material

- Applicable to only low melting point Al alloys (no chance for high-melting-point aluminide intermetallics)
 - Sample should be melted *TiAl, Al₃Ti*
 - Appropriate blowing agents or spacer powder are not available.

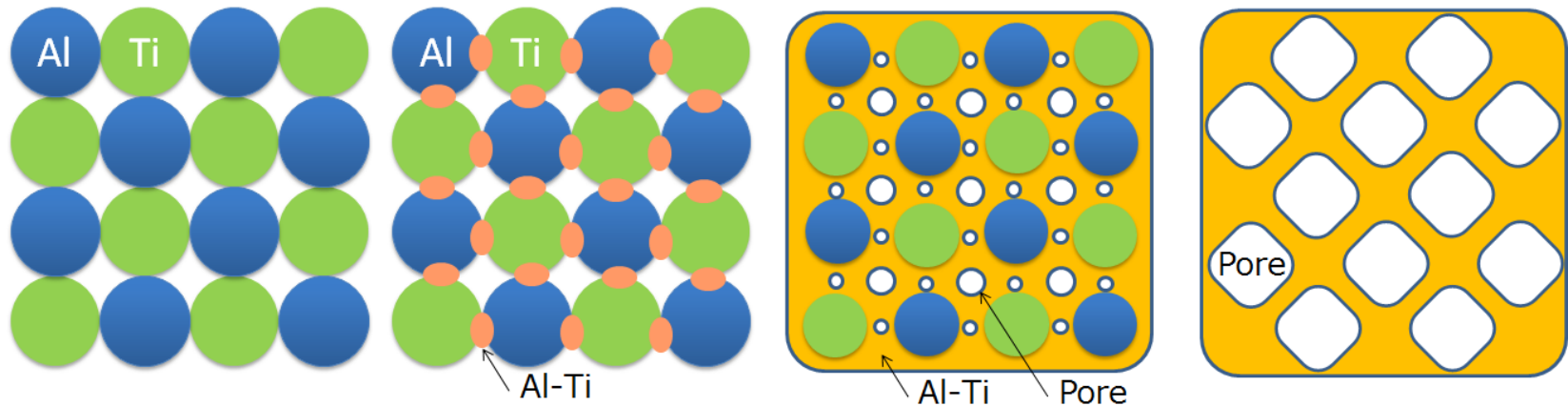
Processing

- Limited sample size
 - limited by furnace size
- Difficult to fill Al hollow components with porous Al
 - Processing temp. is the melting point of aluminum

⇒ Reactive Precursor Process

Reactive precursor process

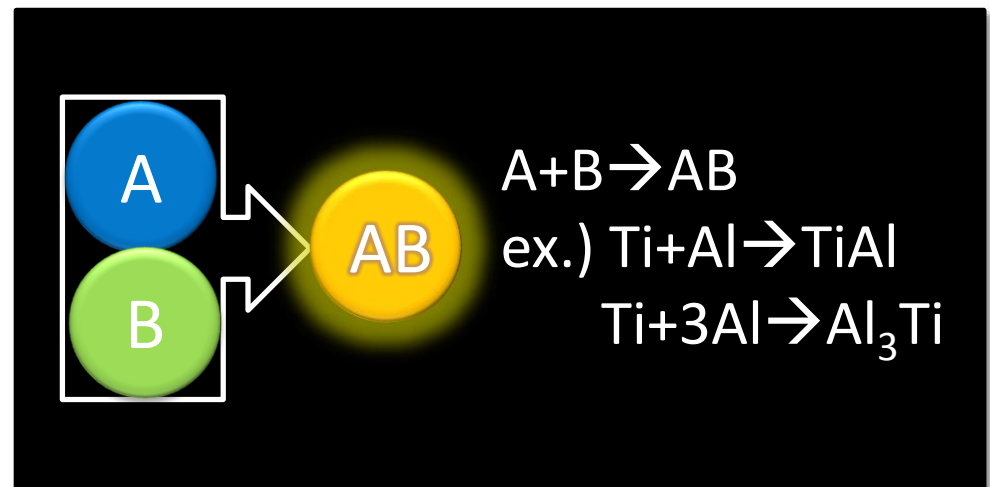
Combustion reaction: a strong exothermic reaction between elemental powders that synthesizes ceramics or intermetallics.



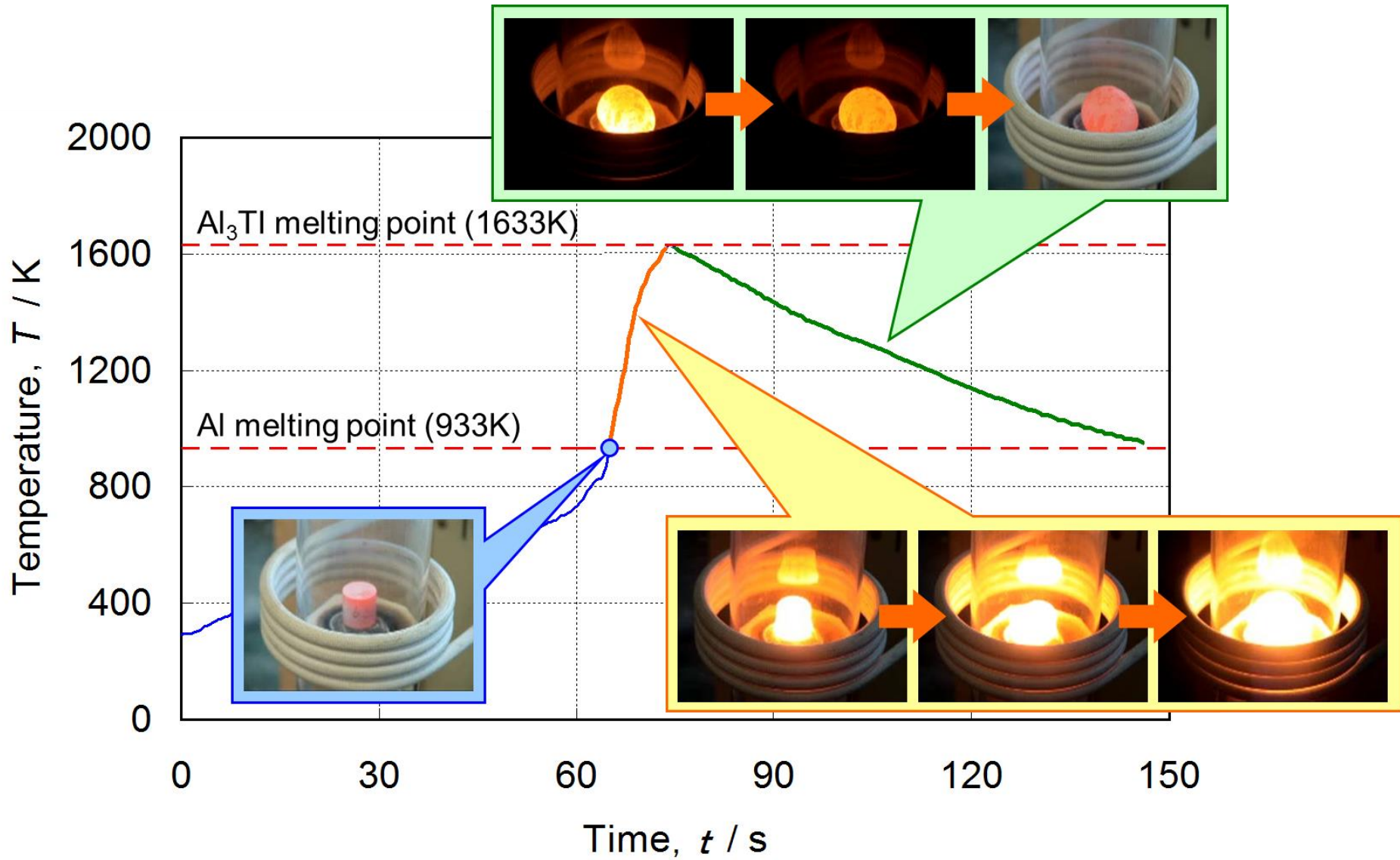
Schematic illustration of combustion reaction between Al and Ti



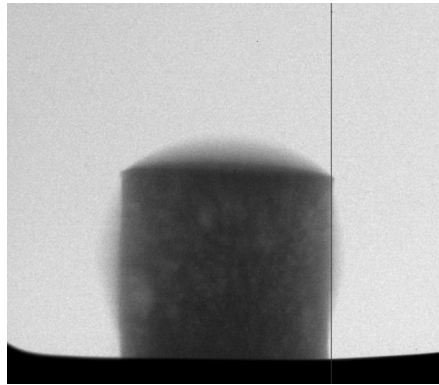
Combustion foaming behavior



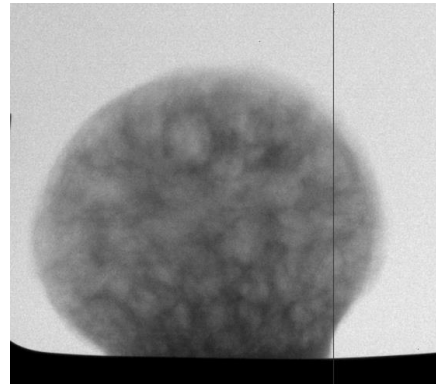
Reactive precursor process



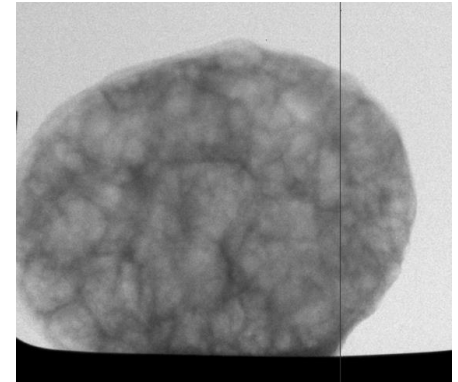
In situ observation of foaming of Al-Ti by X-ray



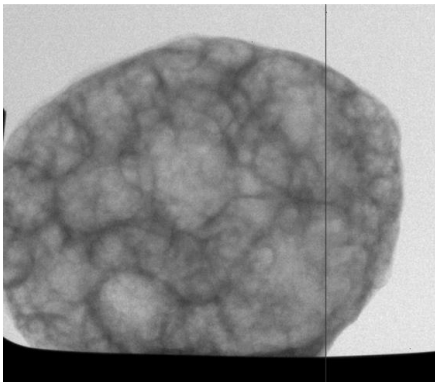
Ignition start



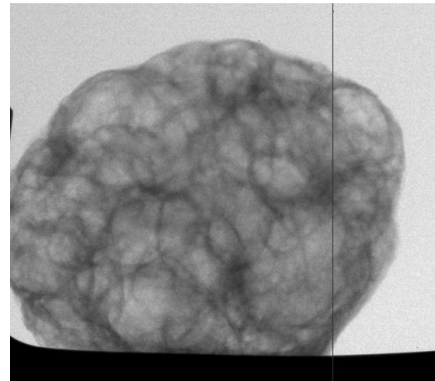
200ms



400ms



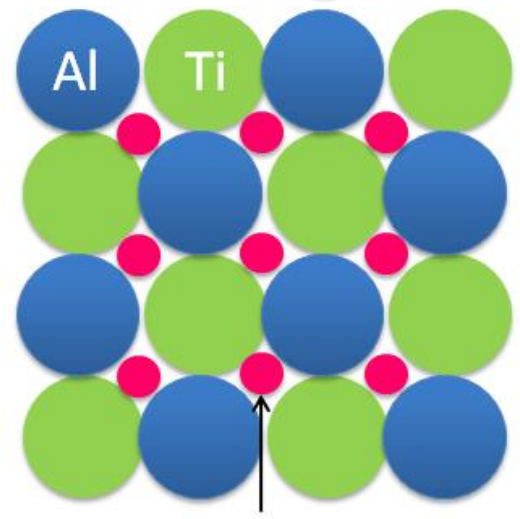
700ms



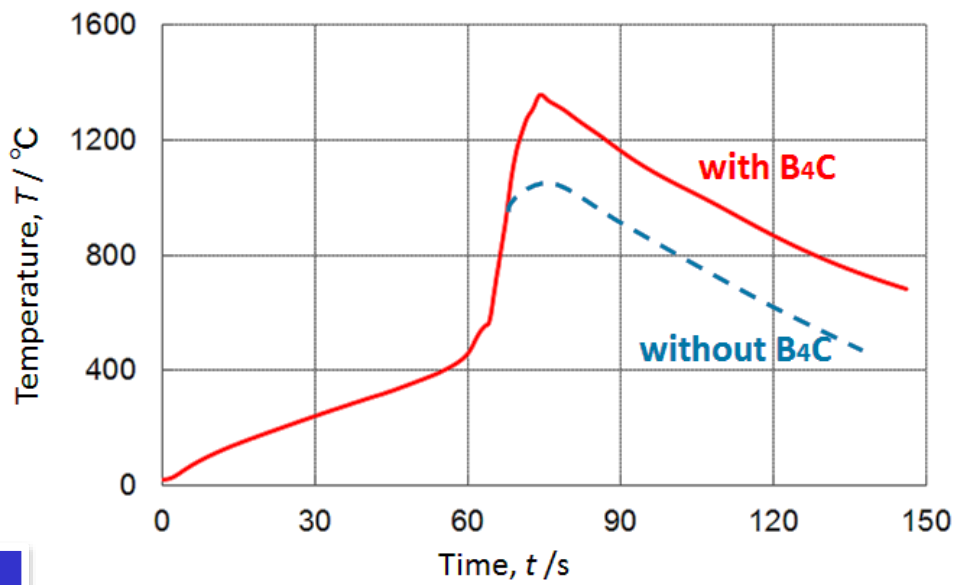
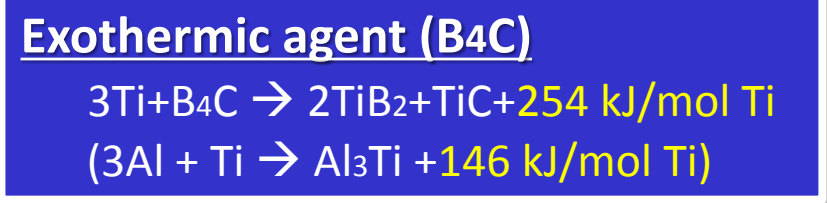
1100ms

Transmission images of a precursor by X-ray during the reaction between Al and Ti

Exothermic agent addition



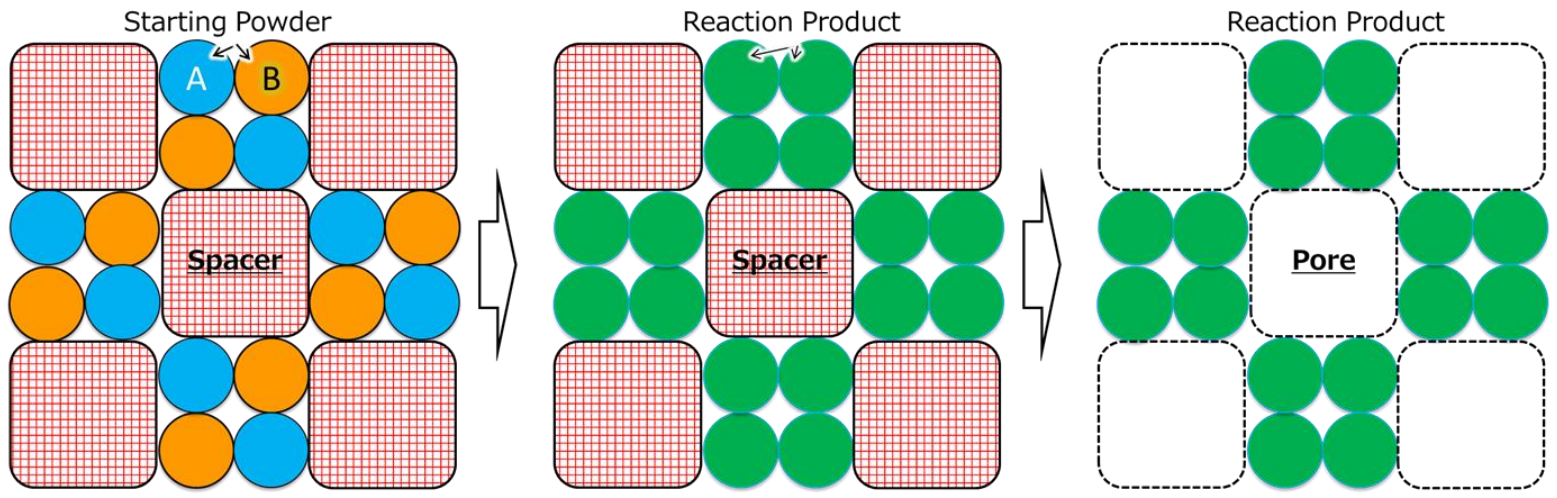
Exothermic agent (B₄C)



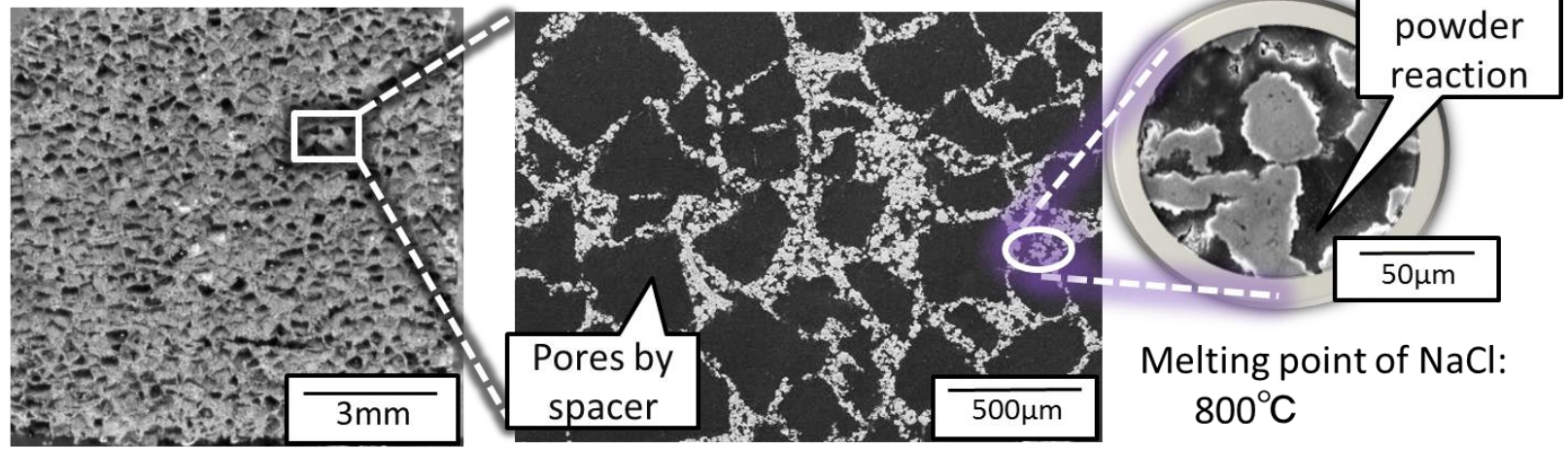
Temperature profile of precursors with and without B₄C additions during heating



Reactive process applied to spacer process

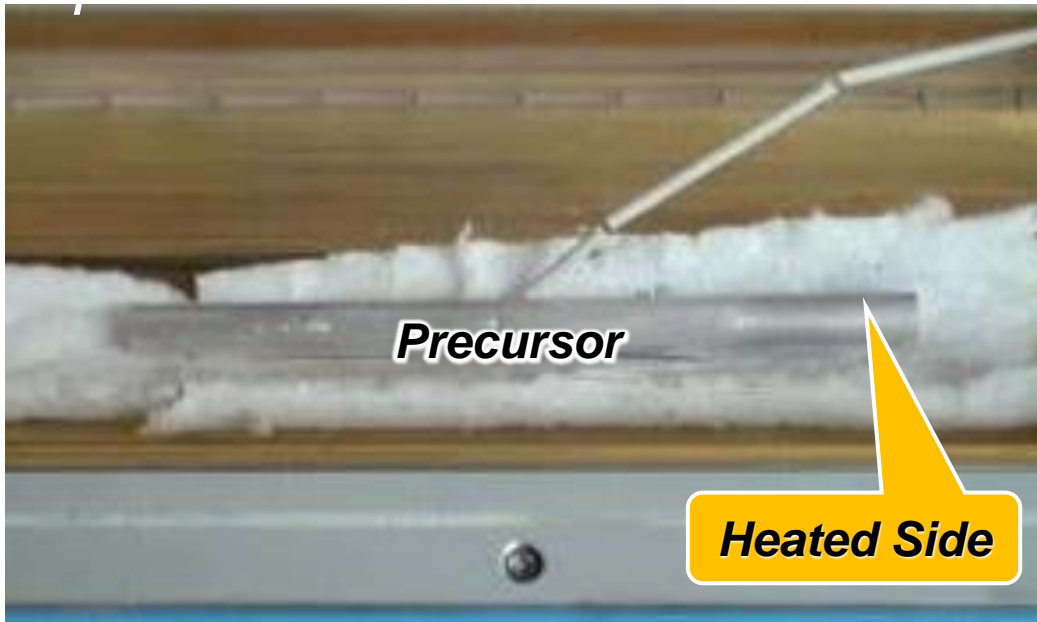


Ex.) Starting reactive powder: Al&Ti (40 μm), Spacer powder: NaCl (400 μm)



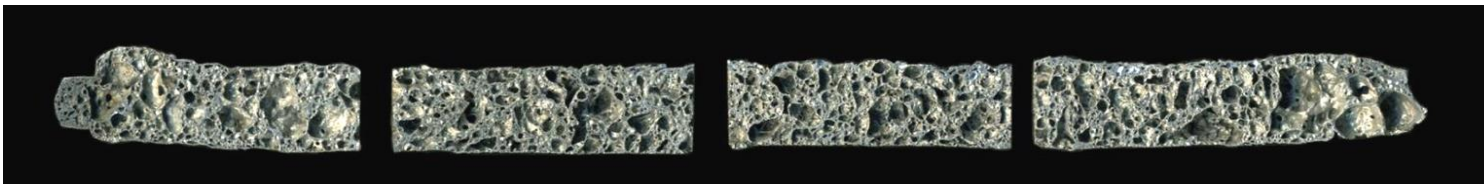
Self-propagating foaming

One of the advantages of the reactive process is that the foaming behavior self-propagates throughout the

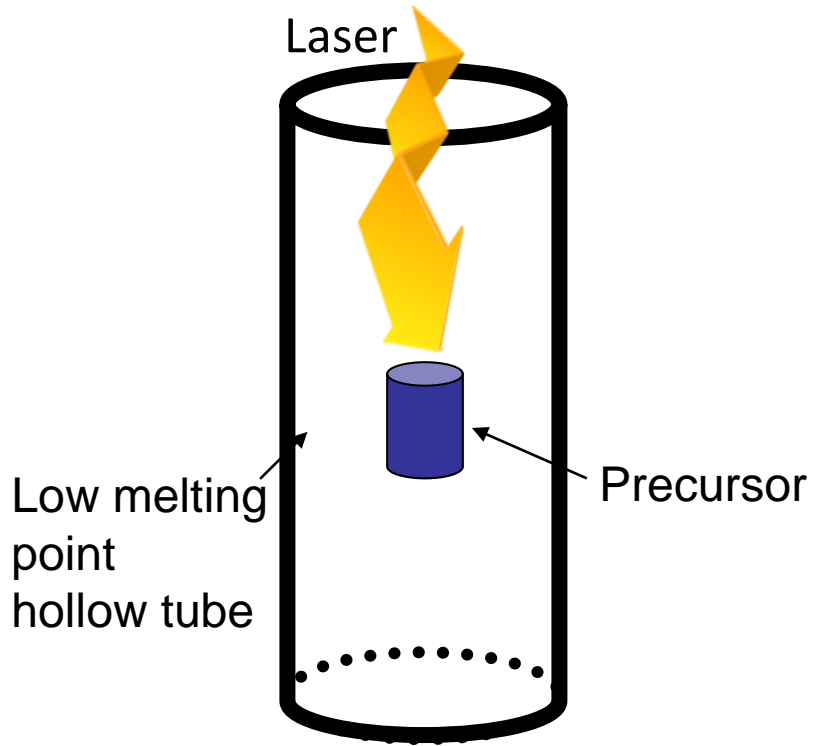


Self-propagation foaming

- Energy saving
- Long or large scale products
- Direct synthesis in hollow component



What we expect for LASER...Ignition tool

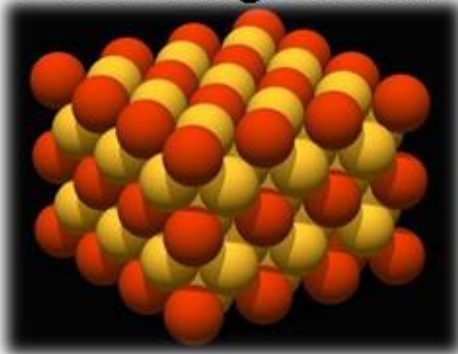


Selective heating of precursor in a hollow component

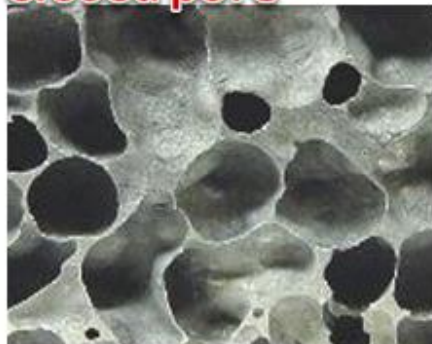


Various morphology achieved by reactive process

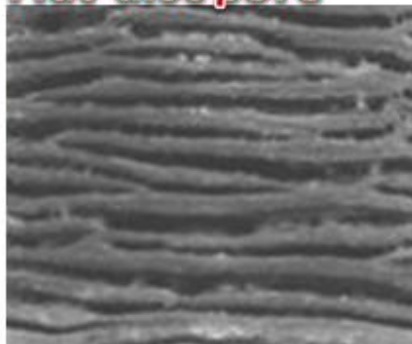
Powder ingredients



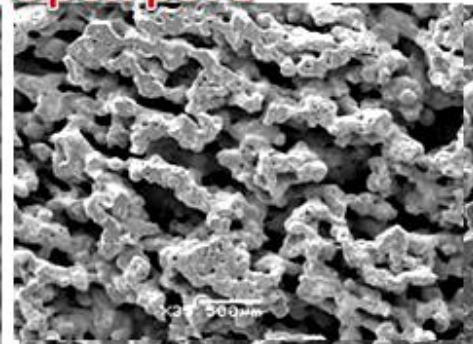
Closed pore



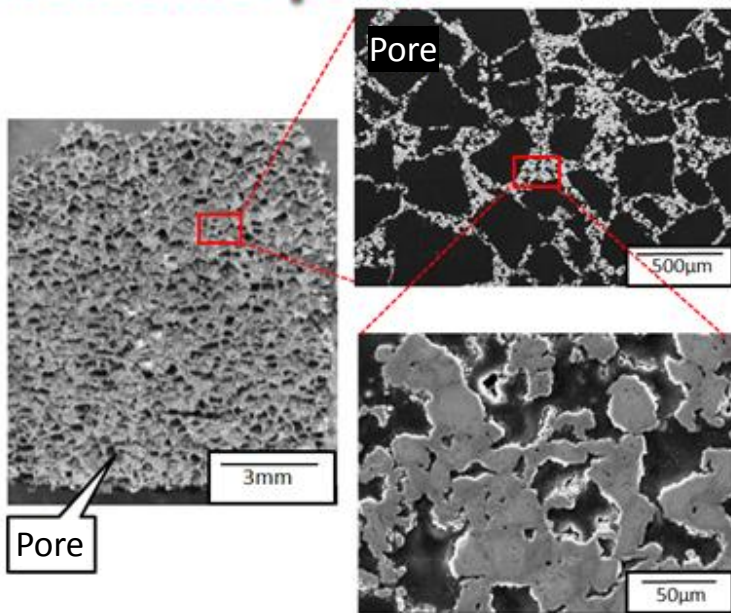
Flat-disc pore



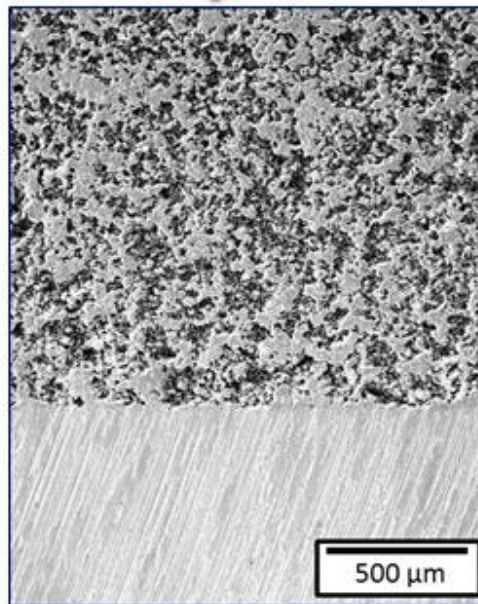
Open pore



Hierarchical pores



Surface pores



Hollow/porous hybrid



Summary

- **Porous metal** is a new class of materials with various unique properties. The most fascinating feature of porous metal is that the properties can be controlled by the shape, size and fraction of the pores.
- **Reactive precursor process** has been studied and various cell morphologies has been achieved so far. The porous metals obtained by this method can be applied to various engineering fields .

Thank you for your kind attention!