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High-efficiency mixing of fine powders via sound assisted fluidized bed for metal foam production by an innovative cold gas dynamic spray deposition method

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AN INNOVATIVE METHOD TO PRODUCE METAL FOAM USING COLD GAS DYNAMIC SPRAY PROCESS ASSISTED BY FLUIDIZED BED MIXING OF PRECURSORS

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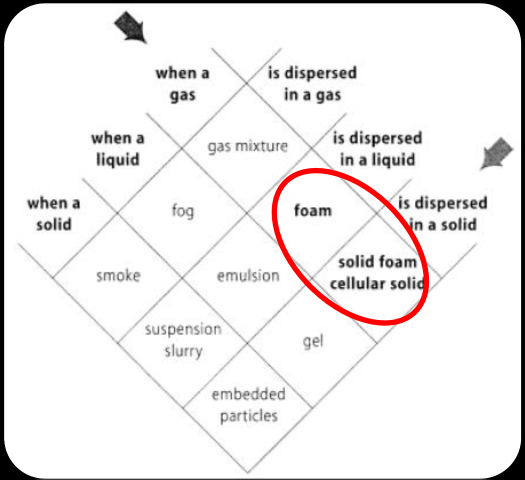
Introduction – Metal foams



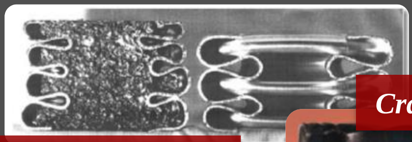
A **metal foam** is a cellular structure consisting of solid metal as well as a large volume fraction of gas-filled pores

Properties

- Low specific weight
- High resistence-to-weight ratio
- Good energy absorption
- High stiffness
- High compression strength
- Mechanical damping properties
- Good fire resistance properties
- Thermal and electrical conductivity

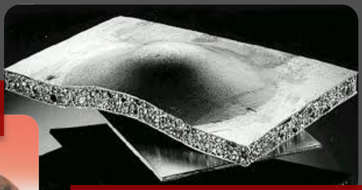
Possible applications

Metal foams of different metals are available, such as: aluminum, nickel, magnesium, lead, zinc, copper, bronze, titanium, steel and even gold. The most used in structural applications are **aluminum foams**

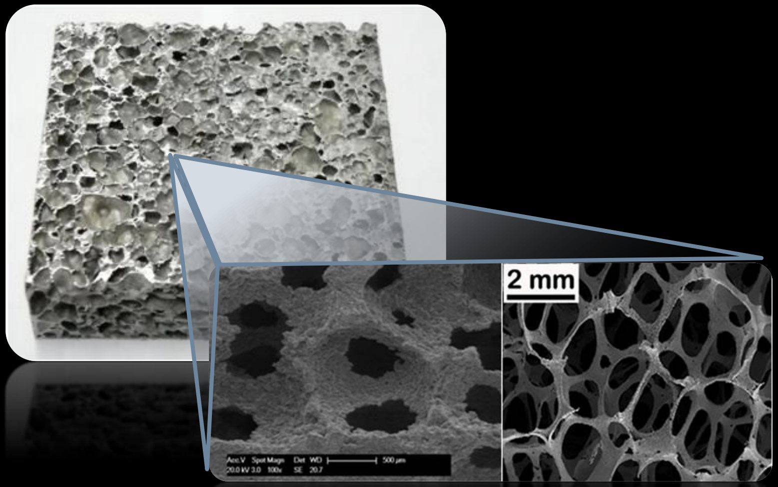


Filling of hollow structures

Crashbars



***Core* of sandwich structures**



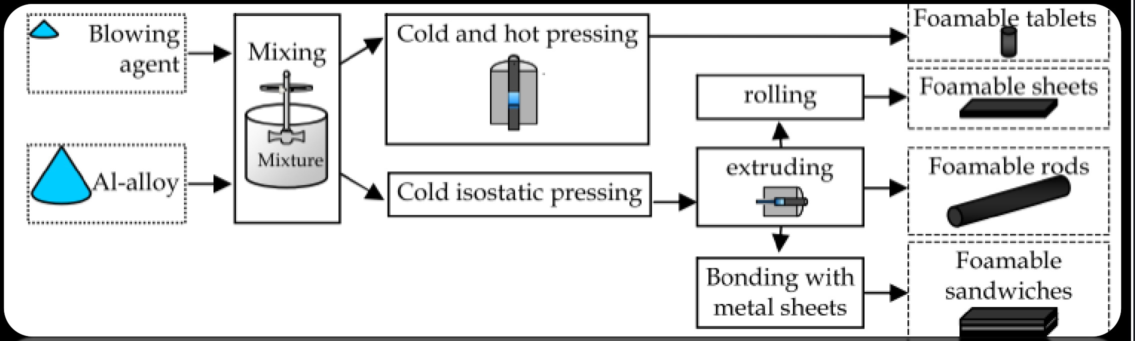
Manufacturing Techniques

There are two fundamental strategies for making metallic foams

Direct foaming
- melt alloy
- make alloy foamable
- create gas bubbles
- collect foam
- solidify foam

Indirect foaming
- prepare foamable precursor
- remelt precursor
- create foam
- solidify foam

Among the indirect methods, the **powder metallurgy** one **(PM)**, in which the starting materials are powders, is of particular interest



- **Starting materials** → *metal powder* *blowing agent*
  - a. mixing of powders
  - b. compaction of mixture
- **Precursor material** → *foamable metal*
  - c. working and cutting
  - d. foaming
- **Final product** → *metal foam*

TiH_2 is the best blowing agent for aluminum foam because releases the largest amount of hydrogen between 400–600° C, which is a temperature range very close to the melting point of aluminum alloys

PM issues

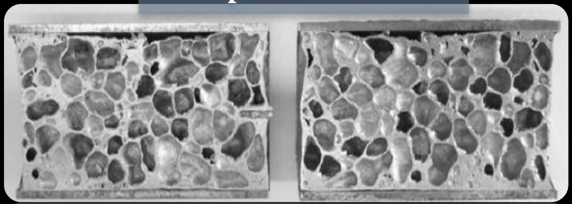
Commercial foaming precursors are only manufactured in form of extruded rods with rectangular cross section

Alulight® Precursor

- 99.2% aluminium and silicon powders
- 0.8 percent titanium hydride

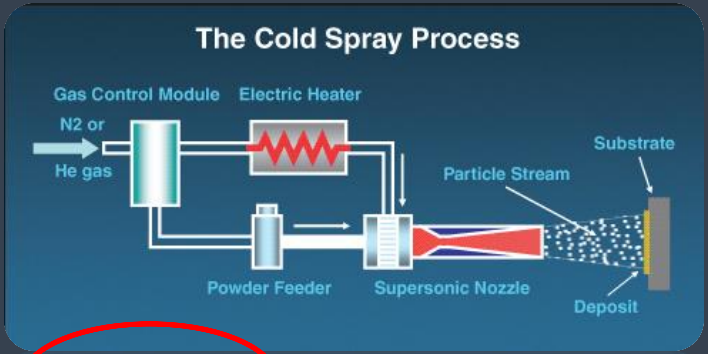
This **rigid geometry** of the precursor limits the applications of these materials, indeed it is very **difficult if not impossible to make complex shaped foamed components**

Simple Geometries



Coupling Issues

Cold gas dynamic spray (CGDS)



A **powder mixture**, made of the aluminum alloy powders and titanium hydride particles, is **sprayed** on a metal substrate and then the foaming process is carried out in order to obtain the final foamed component.

The shape of the precursor can be ruled by using a **complex shaped** substrate or by imposing a **complex trajectory** at the spraying gun.

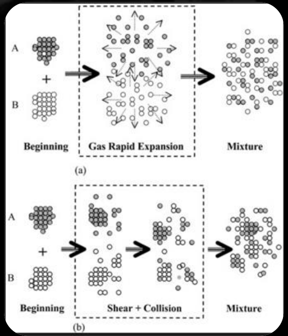
- ✓ Low porosity
- ✓ Possibility to spray on thermally sensitive substrates
- ✓ Possibility to produce thick deposits
- ✓ No oxidation
- ✓ No phase change
- ✓ Minimum surface preparation requirements
- ✓ Simple-to-operate equipment
- ✓ No combsustion fuels or plasma

Powder Mixing

Classical Mixing techniques

- *Tumbling mixers*
- *Convective mixers*
- *High-shear mixers*

suitable for large, non-cohesive particles (i.e. mean particle sizes greater than 30 μm)



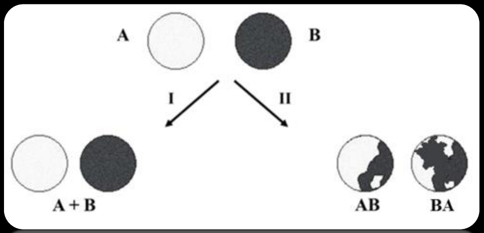
Mixing techniques of fine powders

- *Solvent-based methods*
- *Dry powder methods*
- *Supercritical processing methods*

Alteration of granulometry and nature of powders

Sound Assisted Fluidization

- Does not alter properties and morphology of original particles
- Does not require additional materials
- Easy and cheap to be implemented



In this work

METAL FOAM PRODUCTION BY COLD GAS DYNAMIC SPRAY PROCESS ASSISTED BY FLUIDIZED BED MIXING OF PRECURSORS

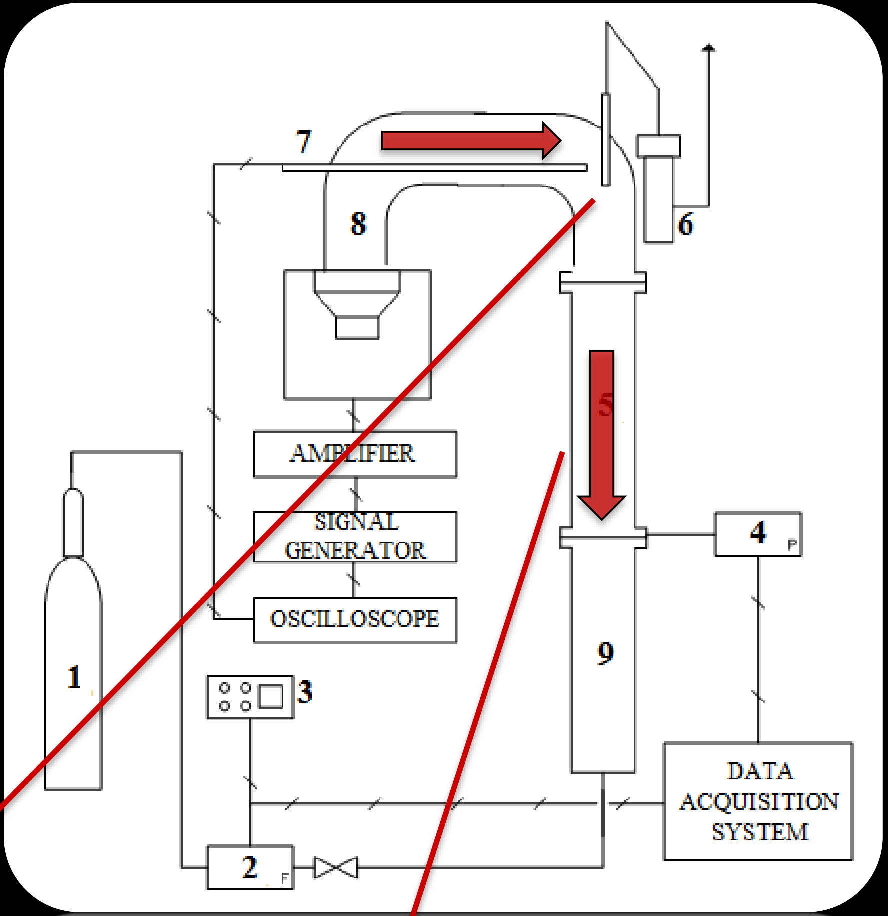
- **Experimental Campaign**
  - *Chemico-physical and fluid-dynamic characterization of the aluminum alloy and the blowing agent powders*
  - *Mixing of the powders in the sound assisted fluidized bed*
  - *Production of the precursor by CGDS and foaming process*

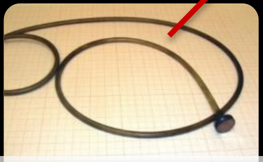
Experimental – Sound assisted fluidized bed

PROCESS PARAMETERS

- Acoustic field intensity : **140 dB**
- Acoustic field frequency: **80 Hz**
- Fluidizing gas: Nitrogen
- Superficial gas velocity: 1.2 cm/s

1. *N_2 cylinder*
2. *Mass flow meter*
3. *Controller*
4. *Pressure transducer*
5. *40mm fluidization column*
6. *Filter*
7. *Microphone*
8. *Sound wave guide*
9. *Wind-box*



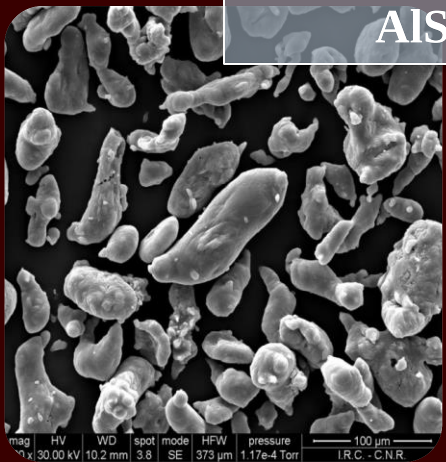


Sampling probe

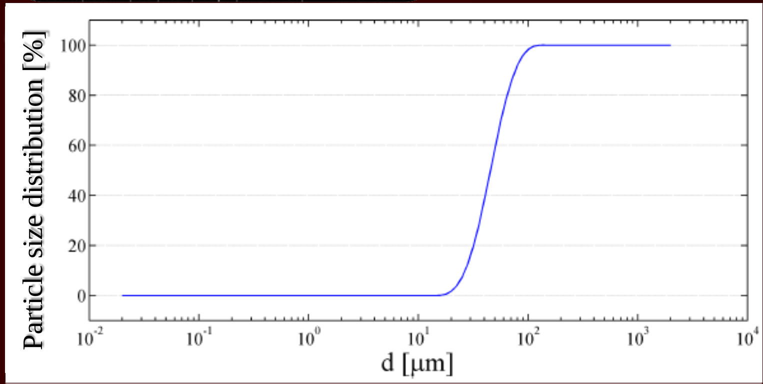
40mm ID fluidization column

Experimental - Materials

AlSi12

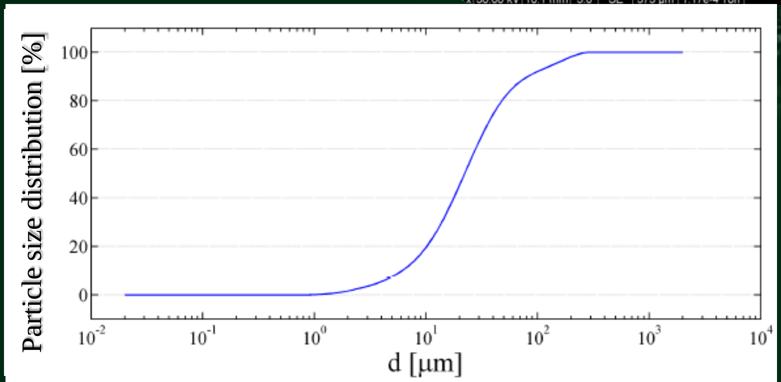


- DYMET
- 12% wt Si
- Te = 577 °C
- $Density = 2.69 g/cm^3$
- **Sauter diameter: 41.9μm**



TiH_2

- DYMET
- Blowing agent
- Te = 450 °C
- $Density = 3.75 g/cm^3$
- **Sauter diameter: 12.9μm**

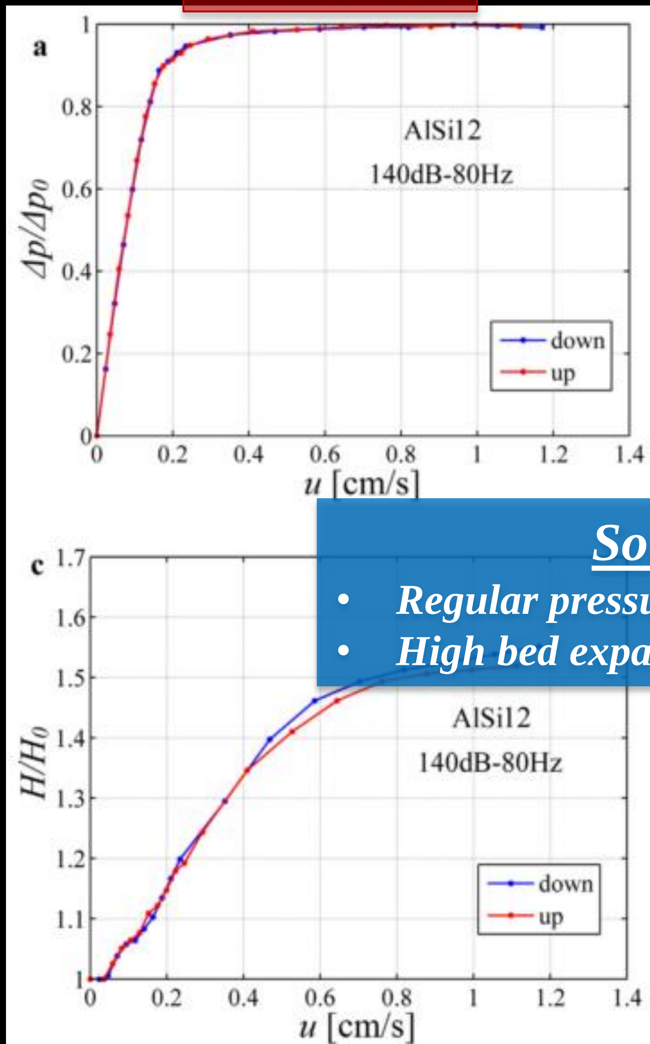


By comparison to the Alulight precursor, a mixture richer in blowing agent, to compensate for possible losses during the subsequent deposition process

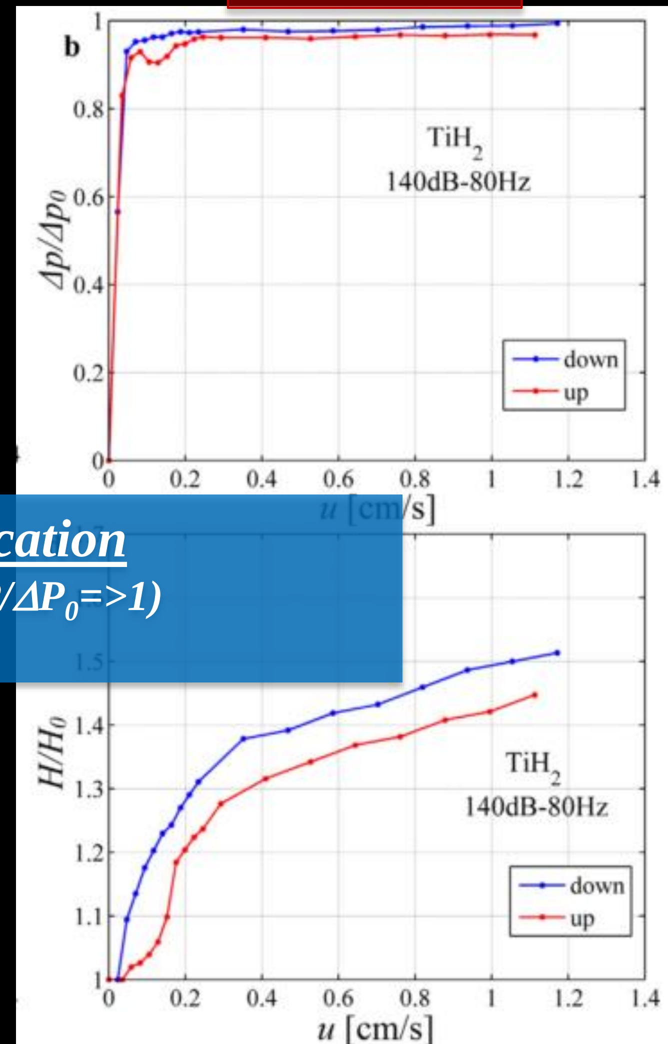
	AlSi12 %wt	TiH_2 %wt
Mixture	97.5	2.5

Results – Fluidization tests

AlSi12



TiH_2

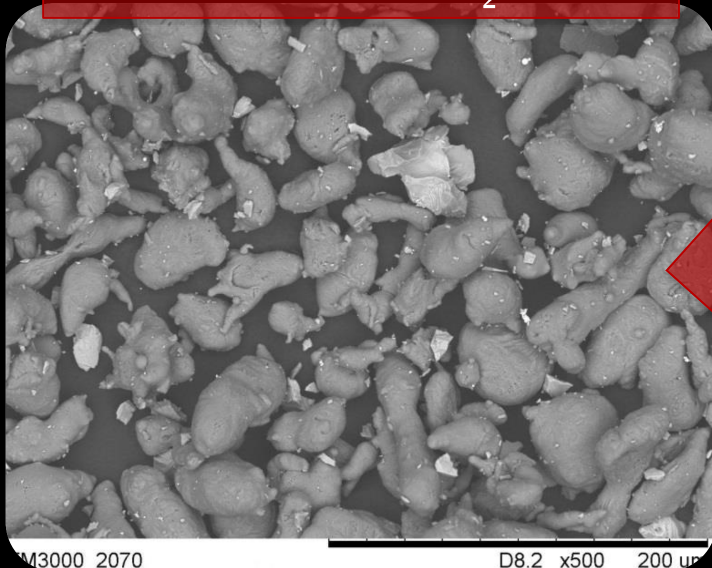


Sound application

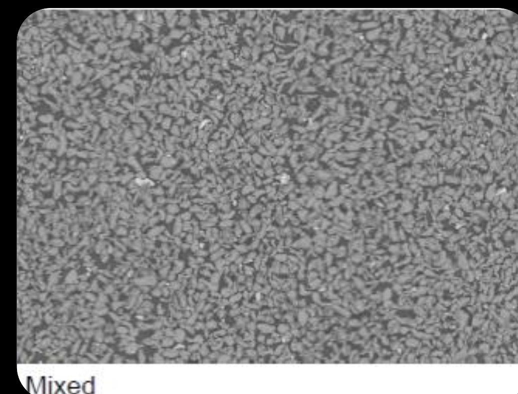
- ***Regular pressure drop ($\Delta P/\Delta P_0$=>1)***
- ***High bed expansion ratios***

Results - Mixing

AlSi12 97.5%wt + TiH_2 2.5%wt

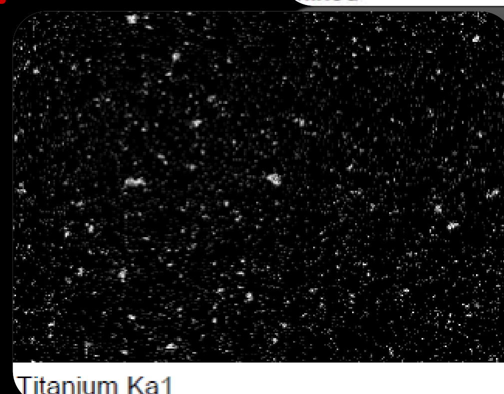


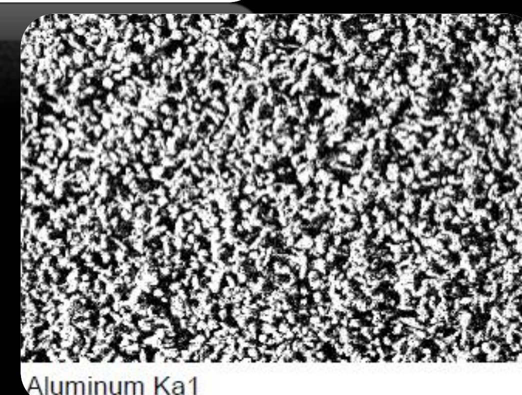
- Titanium hydride (white particles) is well distributed throughout the aluminum-silicon matrix.



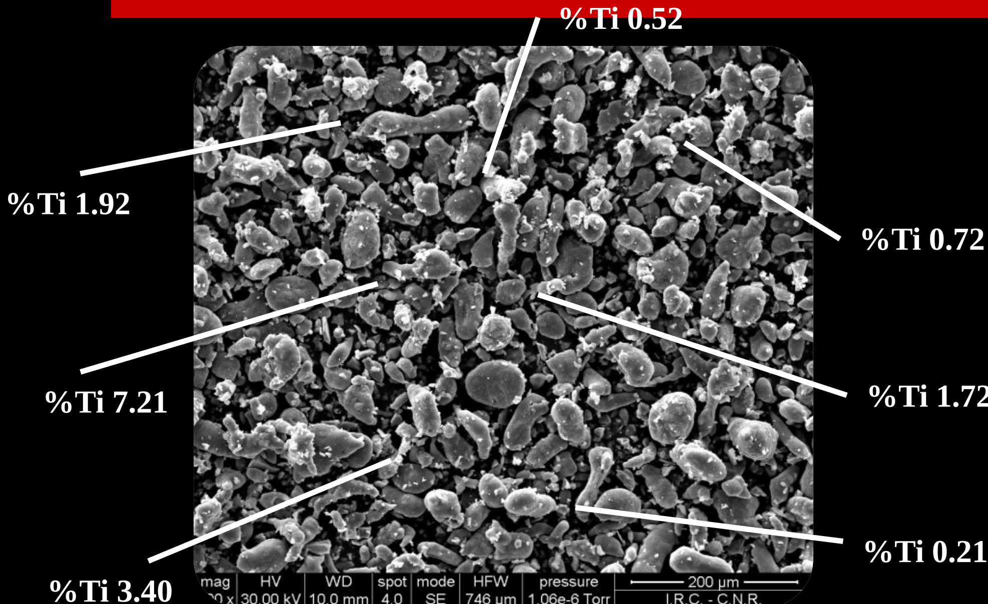
EDS Analysis

Element	%wt	
Al	81.517	✓
Si	10.717	✓
Ti	7.766	✓

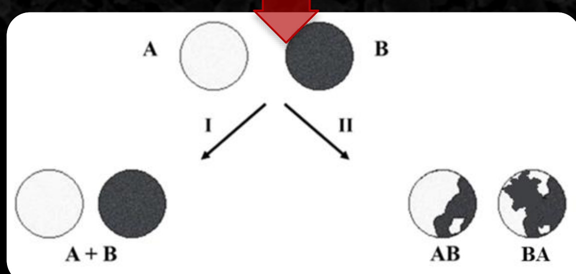




Results – Mixing tests

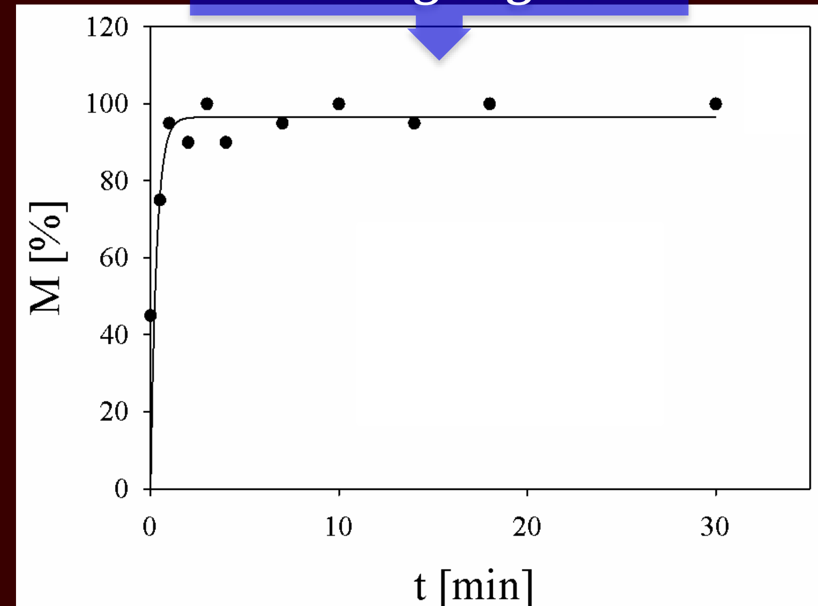


Hybrid aggregates



Due to a **break-up and reaggregation mechanism** the mixing process takes place at the **local scale**, namely not only between aggregates made of only one powder but also **inside aggregates**

Mixing degree



The EDS data were elaborated to evaluate **the time-dependence of the aggregates mixing degree M(t)**

Very short times (about 2 min) are needed for aggregates to be efficiently mixed

Experimental - Cold Gas Dynamic Spray (CGDS) apparatus

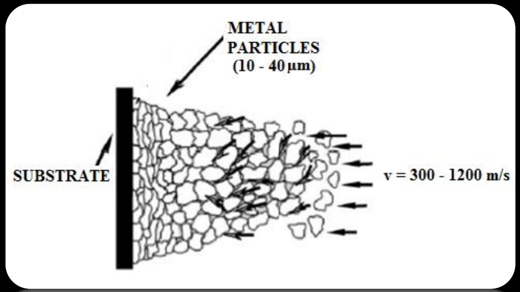
Low Pressure Cold Spray DYMET 423

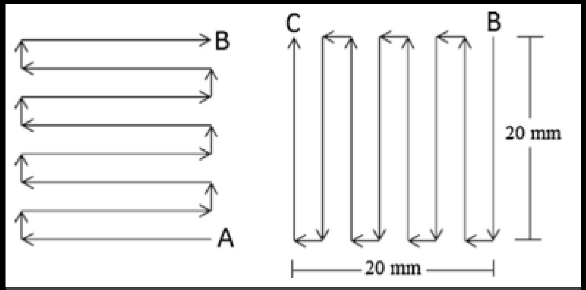
Process Parameters

- Carrier Gas: Helium
- Gas pressure: 7 bar
- Gas temperature: 600°C
- Scan rate: 2.5 mm/s
- Stand-off distance: 5 mm
- Feed rate: 3.5 kg/h

The powder mixture was sprayed on a 0.5 mm stainless steel thin plate; in order to achieve a homogeneous material deposition, the mixture was sprayed according to the scheme reported below

CUSTOMIZED PRECURSORS



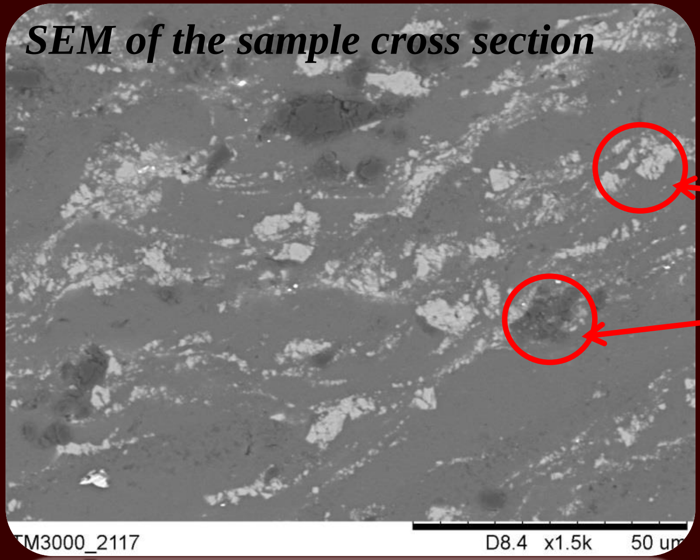


Results - CGDS

Precursor feature

- Thickness : 5 mm
- Coating volume: about 1600 - 2000 mm^3

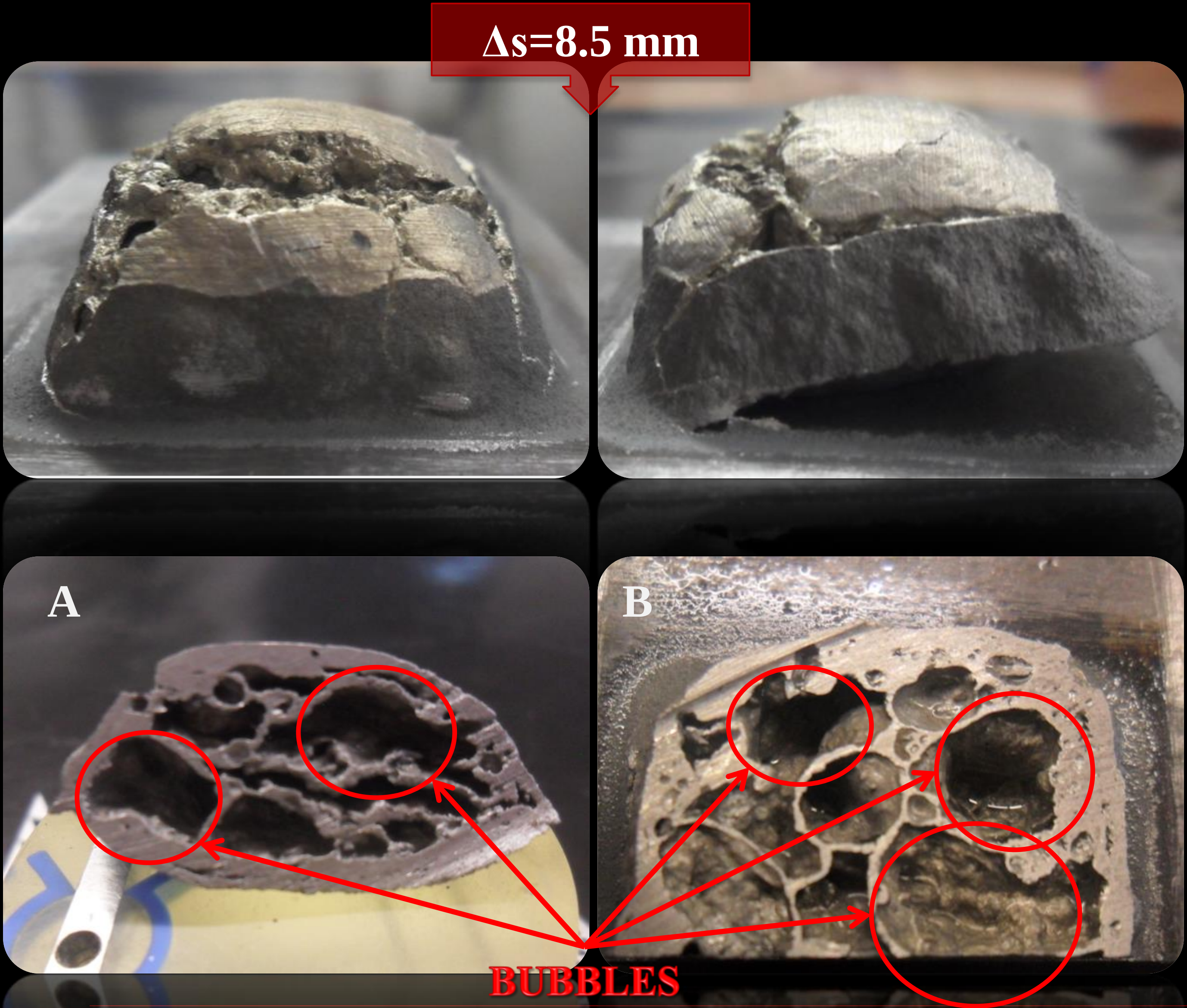
SEM of the sample cross section



- Compact and pore free
- Uniform distribution of blowing agent
- Correct proportion between elements

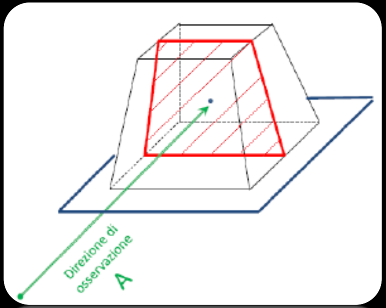
Similar results were obtained using air instead of elium as carrier gas

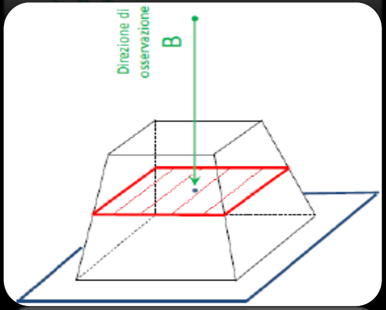
Results - Foaming



Foaming Parameters

- T_f = 650 °C
- t_f = 9 min





Conclusions

- The sound assisted fluidization was proved to be a viable technique to **mix AlSi12 and TiH_2 powders**
- The CGDS technique allowed to manufacture the precursors for the foaming process. Indeed, **compact precursors** with a **homogeneous dispersion** of TiH_2 powders within the aluminum metal matrix were obtained
- The foams obtained from the obtained precursors showed a **well developed cellular structure** after the foaming process

Future improvements

- Refinement of:
  - *The percentage of foaming agent*
  - *The dwell time of the precursor in the oven*
- Bringing down the manufacturing costs by using a **cheaper process gas** in CGDS (such as air or argon) and **smaller percentage of blowing agent**

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Thanks for your kind attention