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

Ammendola P
*Istituto di Ricerche sulla Combustione – CNR, Italy*, paola.ammendola@irc.cnr.it

Raganati F
*Istituto di Ricerche sulla Combustione – CNR, Italy*

Scherillo F
*Istituto di Ricerche sulla Combustione – CNR, Italy*

Squillace A
*Istituto di Ricerche sulla Combustione – CNR, Italy*

Chirone R
*Istituto di Ricerche sulla Combustione – CNR, Italy*

See next page for additional authors

Follow this and additional works at: [http://dc.engconfintl.org/fluidization_xv](http://dc.engconfintl.org/fluidization_xv)

*Part of the* Chemical Engineering Commons

---

**Recommended Citation**

Authors
Ammendola P, Raganati F, Scherillo F, Squillace A, Chirone R, Carrino L, Astarita A, and Viscusi A

This abstract and presentation is available at ECI Digital Archives: http://dc.engconfintl.org/fluidization_xv/106
AN INNOVATIVE METHOD TO PRODUCE METAL FOAM USING COLD GAS DYNAMIC SPRAY PROCESS ASSISTED BY FLUIDIZED BED MIXING OF PRECURSORS

Ammendola P.\textsuperscript{a}, Astarita A. \textsuperscript{b}, Raganati F. \textsuperscript{a}, Scherillo F. \textsuperscript{b}, Squillace A. \textsuperscript{b}, Viscusi A. \textsuperscript{b}, Chirone R. \textsuperscript{a}, Carrino L. \textsuperscript{b}

\textsuperscript{a}Istituto di Ricerche sulla Combustione (CNR) – P.le V. Tecchio 80, 80125 Napoli, Italy
\textsuperscript{b}Department of Chemical, Materials and Industrial Production Engineering, University of Naples Federico II, P.le V. Tecchio 80, 80125, Naples, Italy

FLUIDIZATION XV - 22-27, 2016 - Fairmont Le Chateau Montebello, Quebec, Canada
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 resistance-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.
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**
- a. mixing of powders
- b. compaction of mixture

**Precursor material**
- c. working and cutting
- d. foaming

**Final product**
- metal powder blowing agent
- foamable metal
- metal foam

$\text{TiH}_2$ is the best blowing agent for aluminum foam because it 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

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

Alulight® Precursor
- 99.2% aluminium and silicon powders
- 0.8 percent titanium hydride

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 combustion fuels or plasma

FLUIDIZATION XV - 22-27, 2016 - Fairmont Le Chateau Montebello, Quebec, Canada
Powder Mixing

Classical Mixing techniques
- Tumbling mixers
- Convective mixers
- High-shear mixers

Mixing techniques of fine powders
- Solvent-based methods
- Dry powder methods
- Supercritical processing methods

Suitable for large, non-cohesive particles (i.e. mean particle sizes greater than 30 \( \mu m \))

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. *N₂* 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=2.69g/cm³
- Sauter diameter: 41.9µm

TiH₂
- DYMET
- Blowing agent
- Te = 450 °C
- Density=3.75g/cm³
- 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

<table>
<thead>
<tr>
<th>Mixture</th>
<th>AlSi12 % wt</th>
<th>TiH₂ % wt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixture</td>
<td>97.5</td>
<td>2.5</td>
</tr>
</tbody>
</table>
Results – Fluidization tests

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

**AlSi12**

**TiH$_2$**
Results - Mixing

AI_{1}Si_{12} 97.5\% \text{wt} + TiH_{2} 2.5\% \text{wt}

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

<table>
<thead>
<tr>
<th>EDS Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Element</td>
</tr>
<tr>
<td>Al</td>
</tr>
<tr>
<td>Si</td>
</tr>
<tr>
<td>Ti</td>
</tr>
</tbody>
</table>
Results – Mixing tests

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.

Hybrid aggregates

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.
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 helium as carrier gas

Mixture: AlSi12 97.5 + TiH$_2$ 2.5\% wt
Carrier gas: Helium
Results - Foaming

Δs = 8.5 mm

Foaming Parameters
- $T_f = 650 \degree C$
- $t_f = 9 \text{ min}$
Conclusions

- The sound assisted fluidization was proved to be a viable technique to mix AlSi12 and TiH₂ powders.

- The CGDS technique allowed to manufacture the precursors for the foaming process. Indeed, compact precursors with a homogeneous dispersion of TiH₂ 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.
AN INNOVATIVE METHOD TO PRODUCE METAL FOAM USING COLD GAS DYNAMIC SPRAY PROCESS ASSISTED BY FLUIDIZED BED MIXING OF PRECURSORS

Ammendola P.\textsuperscript{a}, Astarita A.\textsuperscript{b}, Raganati F.\textsuperscript{a}, Scherillo F.\textsuperscript{b}, Squillace A.\textsuperscript{b}, Viscusi A.\textsuperscript{b}, Chirone R.\textsuperscript{a}, Carrino L.\textsuperscript{b}

\textsuperscript{a}Istituto di Ricerche sulla Combustione (CNR) – P.le V. Tecchio 80, 80125 Napoli, Italy
\textsuperscript{b}Department of Chemical, Materials and Industrial Production Engineering, University of Naples Federico II, P.le V. Tecchio 80, 80125, Naples, Italy

Thanks for your kind attention