Nanomaterials as an occupational risk in metal additive manufacturing

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AGENDA

- Wide approach to Additive Manufacturing (AM)
- Occupational exposure to nanomaterials during AM processes
- Risk assessment of occupational exposure to nanomaterials
- Risk assessment of exposure to nanomaterials during AM processes
- Conclusions
- Next steps
Additive Manufacturing

“Process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies.”

(ISO/ASTM 52900:2015)

- **Goal**: create three-dimensional parts by successive additions of materials
**Benefits**

- Variety of raw materials and applications;
- Single machine for all process, no need to use additional dies;
- Less waste;
- Customized parts;
- …

**Disadvantages**

- Inability to mass production;
- Often time-consuming process and high investment;
- Risks not yet sufficiently known;
- …
Metal additive manufacturing

- Different raw materials;
- Impact on health and safety related mainly to particulate emissions: coarse, fine and ultrafine;
- Health effects of metal nanoparticles are well-known hazards in other metal processing activities such as welding.
AND SO RESEARCH BEGINS
EXPOSURE TO NANOMATERIALS

START
Exposure to Nanomaterials: What’s the risk?

OCCUPATIONAL EXPOSURE TO NANOMATERIALS

- Toxic effects
- Impact on human health
- Environmental impact
- Challenges

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Quantitative methods

- Several alternatives to assess exposure, based on:
  - Number concentration;
  - Mass concentration;
  - Morphology;
  - Chemical composition;
  - ...
Obstacles on the way

Quantitative methods

- Difficult to choose the most appropriate methods;
- Difficult to choose the most proper sampling techniques;
- Specific equipment is required and has some limitations;
- OELs are not defined for all nanomaterials;
- ....
Qualitative and semiquantitative methods

- Control Banding Nanotool
- Stoffenmanager Nano
- Anses Tool
- NanoSafer CB
- Precautionary Matrix for Synthetic Nanomaterials
- Monte Carlo Simulation Model
- Decision Tree Analysis, Multicriteria Decision Analysis
- Bayesian Analysis
- Systematic Design Analysis Approach
- …
More obstacles on the way

Qualitative and semiquantitative methods

- Difficult to choose the most appropriate method;
- Applications are often specific;
- Difficult to gather some input data;
- Not yet validated.
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Focus on metal additive manufacturing and find out what’s already been done...
Occupational exposure to nanomaterials during metal additive manufacturing

- Diversity of raw materials and technologies;
- **Most common processes**: Power Bed Fusion and Direct Energy Deposition;
- Tasks that require direct contact with metal powder.
Literature review

- Published between 1990 – 2018;
- Peer reviewed publications;
- Written in English;
- Regarding emissions during metal AM;
- Real occupational conditions.
Literature review


## RISK ASSESSMENT OF EXPOSURE TO NANOMATERIALS DURING METAL AM

### STUDY #1

**Aim**
To use measuring techniques optimized for different particle sizes while analyzing numbers, sizes, masses and identities of metal particle emissions

**Material**
Chromium, nickel and cobalt alloy (both virgin and used powder)

**AM Technique**
Selective laser melting (SLM)

**Quantitative Analysis**
- **Nanotracer** (10 to 300 nm);
- **Lighthouse** (300 nm to 10 μm);
- **Traditional filter-based** particle mass estimation + inductively coupled plasma mass spectrometry

### STUDY #2

**Aim**
To examine metal 3D printing, composite manufacturing and fabric production in terms of generated nano-sized by-products during production

**Material**
Nickel-base Inconel 939 (both virgin and used powder)

**AM Technique**
Selective laser melting (SLM)

**Quantitative Analysis**
- **Scanning electron microscopy (SEM)**
- **Energy Dispersive Spectrometer (EDS)**

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## Risk Assessment of Exposure to Nanomaterials During Metal AM

<table>
<thead>
<tr>
<th>STUDY #1</th>
<th>STUDY #2</th>
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<tbody>
<tr>
<td><strong>RESULTS</strong></td>
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<tr>
<td>• Nanosized particles are generated during metal AM;</td>
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<td>• Operators are exposed mainly while handling powder;</td>
<td>• Presence of nanosized particles in samples with recycled powder.</td>
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<td>• Particle sizes tended to be smaller in recycled powder.</td>
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<tr>
<th><strong>RECOMMENDATIONS</strong></th>
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<tr>
<td>• Improve powder handling systems;</td>
<td>• Powder handling in a confined space;</td>
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<tr>
<td>• Measurement techniques for nanosized particles;</td>
<td>• Personal protective equipment;</td>
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<tr>
<td>• Work environment regulations;</td>
<td>• Good ventilation with HEPA filters;</td>
</tr>
<tr>
<td>• Personal protective equipment;</td>
<td>• Include information in the safety data sheet for powder intended to be used in metal 3D printing;</td>
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<td>• Regular metal analyses of urine.</td>
<td>• Training for workers.</td>
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Studies prove that there is occupational exposure to nanomaterials during metal additive manufacturing;

Not many studies are available in this field, although AM is a promising and emergent technology;

Opportunity:
- Explore and improve occupational risk management in metal AM;
- Collect new relevant data to the scientific community;
- Provide a contribution to the protection of workers that are working with this recent technology in the metalworking field.
GOAL

Development of a risk management framework regarding the occupational risk of exposure to nanomaterials emitted during metal additive manufacturing processes.


There is a lot to work to do to get to the finish line...
NEXT STEPS

- **Data collection (case study):** raw materials, products generated, all tasks performed, ...;

- **Qualitative approach** (Control Banding & Systematic Design Analysis Approach*);

- **Quantitative approach** (CPC; SEM; ...);

- **Definition of control actions** to be implemented based on results;

- **Design of a risk management framework** for occupational risk of exposure to nanomaterials emitted during metal AM.

* Silva, Francisco, Arezes, Pedro, & Swuste, Paul (2015)
Thank you for your attention!

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