On the toxicological effects of airborne nanoparticles from welding processes

João F Gomes

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On the toxicological effects of airborne nanoparticles from welding processes

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Welding fume

Most welding processes result in the emission of welding fume:

- airborne particles,
- gases,
- metal projections,

that are potentially hazardous. This usually requires the use of forced extraction and ventilation devices, as well as masks.
Welding fume

Nature and composition of welding fume depends of:

- type of process,
- type of base metal and deposited metal,
- type of gaseous protection,
- specific process parameters.

[Pierves et al., 2007]
Airborne Nanoparticles

The emission of fine particles (PM2.5: <2.5µm and PM10: <10µm) was already demonstrated. It is possible that smaller (<1µm and in nano range) particles are emitted also.

The smaller the particle, the more potentially hazardous it gets as it can go deeper inside the respiratory system.
Airborne Nanoparticles

For particles $> 2.5 \, \mu m$, toxicity is dependant of chemical nature. Toxicity is already well determined and exposure limits (defined by ACGIH, NIOSH, ... ) are defined in terms of:

- TWA (time weighted average: 8 h exposure)
- instantaneous concentration (15 min exposure)

ACGIH has assigned welding fumes (not otherwise classified) a threshold limit value (TLV) of 5 milligrams per cubic meter ($mg/m^3$) as a TWA for a normal 8-hour workday and a 40-hour workweek [ACGIH 1994, p. 36].
Airborne Nanoparticles

The main distinctive character of nanoparticles vs macroparticles is the high value of superficial area.

Nanoparticles can be toxic depending on the shape and penetration potential inside pulmonary system.
Nanoparticles exposure assessment

2.5 µm particles stop at larynx. Nanoparticles can go as deep as tracheobronquial or even alveolar region.

Alveolar penetration is the most dangerous one as nanoparticles can enter the blood stream and distributed all over the human body.
ICRP / ACGIH Model

A model was developed comprising deposition curves for nanoparticles in different regions of the lung for typical workers.

Deposition curves for particles in tracheobronchial and alveolar regions of the lung.
Measurements using the Nanoparticle Surface Area Monitor (NSAM)

**Operation schematic**

NSAM – TSI, Model 3550

Measured:
- deposited area of particles vs. lung region area ($\mu$m$^2$/m$^2$)
Experimental set-up for exposure assessment in MAG and TIG welding

Monitoring equipment

Sampling ports:
- 30 cm
- 60 cm
- welding mask
# Measurements overview

<table>
<thead>
<tr>
<th>Sample</th>
<th>Date</th>
<th>Instrument ID</th>
<th>8-hr TWA</th>
<th>Mean (μm²/cm²)</th>
<th>Std. Dev. (μm²/cm²)</th>
<th>Min. (μm²/cm²)</th>
<th>Max. (μm²/cm²)</th>
<th>Sample Length (hh:mm:ss)</th>
<th>Avg. Interval (ss)</th>
<th>8-hr TWA (μm²/cm²)</th>
<th>Total Deposited Surface Area (μm²)</th>
<th>Dose per unit Lung Mass (μm²/μg)</th>
<th>Dose per unit Lung Area (μm²/μm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample I</td>
<td>08-04-2011</td>
<td>11:05</td>
<td>1.65</td>
<td>158.6</td>
<td>41.1</td>
<td>112.8</td>
<td>329.9</td>
<td>06:00</td>
<td>10</td>
<td>1.65</td>
<td>7.53e+05</td>
<td>7.93e+05</td>
<td>9.97e+03</td>
</tr>
</tbody>
</table>

**Graph:**

- **Y-axis:** Deposited Surface Area (μm²/cm²)
- **X-axis:** Time (Fri 8 Apr 2011 from 11:05 to 11:10)

**Notes:**

- The measurements were taken over the 8-hour period from 11:05 to 11:10 on Friday, 8th April 2011.
- The running average is shown in the graph.

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# Measurements for TIG welding of carbon steel

<table>
<thead>
<tr>
<th>Welding conditions</th>
<th>Sampling location</th>
<th>Average deposited area (µm²/cm³)</th>
<th>Minimum and maximum values (µm²/cm³)</th>
<th>TWA for 8h (µm²/cm³)</th>
<th>Total deposited area (µm²)</th>
<th>Dose per lung area (µm²/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>no welding Baseline</td>
<td>-</td>
<td>134.8</td>
<td>126.9 – 144.4</td>
<td>2.15</td>
<td>1.03 x 10⁶</td>
<td>1.29 x 10⁴</td>
</tr>
<tr>
<td>120 A</td>
<td>Welder mask</td>
<td>6240</td>
<td>117.9 - 23300</td>
<td>54.2</td>
<td>2.60 x 10⁷</td>
<td>3.25 x 10⁵</td>
</tr>
<tr>
<td>90 A</td>
<td>60 cm from welding</td>
<td>158.6</td>
<td>112.8 – 329.9</td>
<td>1.65</td>
<td>7.93 x 10⁵</td>
<td>9.91 x 10³</td>
</tr>
<tr>
<td>120 A</td>
<td>60 cm from welding</td>
<td>174.7</td>
<td>124.9 – 256.4</td>
<td>0.97</td>
<td>4.66 x 10⁵</td>
<td>5.28 x 10³</td>
</tr>
<tr>
<td>210 A</td>
<td>60 cm from welding</td>
<td>503.4</td>
<td>353.5 - 1080</td>
<td>3.15</td>
<td>1.51 x 10⁶</td>
<td>1.89 x 10⁴</td>
</tr>
</tbody>
</table>

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# Measurements for MAG welding of carbon steel

<table>
<thead>
<tr>
<th>Welding conditions</th>
<th>Sampling location</th>
<th>Average deposited area (µm²/cm³)</th>
<th>Minimum and maximum values (µm²/cm³)</th>
<th>TWA for 8h (µm²/cm³)</th>
<th>Total deposited area (µm²)</th>
<th>Dose per lung area (µm²/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>no welding Baseline</td>
<td>-</td>
<td>107.8</td>
<td>67.2 – 193.9</td>
<td>2.99</td>
<td>1.44 x 10⁶</td>
<td>1.80 x 10⁴</td>
</tr>
<tr>
<td>120 A</td>
<td>Welder mask</td>
<td>24300</td>
<td>7270 - 66400</td>
<td>75.9</td>
<td>3.64 x 10⁷</td>
<td>4.55 x 10⁵</td>
</tr>
<tr>
<td>210 A</td>
<td>Welder mask</td>
<td>69100</td>
<td>42100 - 92200</td>
<td>120.0</td>
<td>5.76 x 10⁷</td>
<td>7.20 x 10⁵</td>
</tr>
<tr>
<td>285 A</td>
<td>Welder mask</td>
<td>96400</td>
<td>82600 – 100000</td>
<td>234.2</td>
<td>1.12 x 10⁸</td>
<td>1.41 x 10⁵</td>
</tr>
<tr>
<td>210 A</td>
<td>30 cm from welding</td>
<td>840.5</td>
<td>452.5 - 1050</td>
<td>2.63</td>
<td>1.26 x 10⁶</td>
<td>1.58 x 10⁴</td>
</tr>
<tr>
<td>120 A</td>
<td>60 cm from welding</td>
<td>353.0</td>
<td>309.4 – 378.8</td>
<td>0.98</td>
<td>4.71 x 10⁵</td>
<td>5.88 x 10³</td>
</tr>
<tr>
<td>210 A</td>
<td>60 cm from welding</td>
<td>833.6</td>
<td>765.8 – 916.7</td>
<td>2.03</td>
<td>9.73 x 10⁵</td>
<td>1.22 x 10⁴</td>
</tr>
<tr>
<td>285 A</td>
<td>60 cm from welding</td>
<td>1070</td>
<td>946.7 - 1180</td>
<td>2.22</td>
<td>1.07 x 10⁶</td>
<td>1.33 x 10⁴</td>
</tr>
</tbody>
</table>

*Measurements for MAG welding of carbon steel.*

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Experimental set-up for exposure assessment in Friction-Stir welding

Monitoring equipment

FSW tool
# Measurements for FSW of aluminum (AA7178-T6)

<table>
<thead>
<tr>
<th>Welding conditions</th>
<th>Sampling location</th>
<th>Average deposited area (µm²/cm³)</th>
<th>Minimum and maximum values (µm²/cm³)</th>
<th>TWA for 8h (µm²/cm³)</th>
<th>Total deposited area (µm²)</th>
<th>Dose per lung area (µm²/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>no welding</td>
<td>-</td>
<td>64.0</td>
<td>61.5 – 68.0</td>
<td>2.11</td>
<td>1.01 x 10⁶</td>
<td>1.27 x 10⁴</td>
</tr>
<tr>
<td>355 mm/min Cold</td>
<td>Welding tool</td>
<td>2500</td>
<td>56.0 - 13900</td>
<td>6.95</td>
<td>3.34 x 10⁶</td>
<td>4.17 x 10⁴</td>
</tr>
<tr>
<td>180 mm/min Hot</td>
<td>Welding tool x 225</td>
<td>16500</td>
<td>59.4 - 100000</td>
<td>160.3</td>
<td>7.70 x 10⁷</td>
<td>9.62 x 10⁵</td>
</tr>
<tr>
<td>355 mm/min Cold</td>
<td>Welding tool</td>
<td>15700</td>
<td>38.6 - 100000</td>
<td>114.5</td>
<td>5.49 x 10⁷</td>
<td>6.87 x 10⁵</td>
</tr>
<tr>
<td>180 mm/min Cold</td>
<td>Welding tool x 166</td>
<td>10600</td>
<td>11.0 - 42500</td>
<td>40.6</td>
<td>1.95 x 10⁷</td>
<td>2.44 x 10⁵</td>
</tr>
</tbody>
</table>
Conclusions

- The presence of airborne nanoparticles, resulting from welding processes, was detected by comparison with the baseline values.

- For MAG and TIG processes the highest values are obtained for the highest current intensities applied: the more energy intensive processes are, the higher the amounts of airborne particles that are emitted (the same occurs with macroparticles).

- TIG seems “cleaner” than MAG.

- The highest values are obtained in the welder mask and in locations close to the welding front.

- A marked decay of nanoparticles with the distance to the weld area is observed.
Conclusions

- In FSW, the presence of airborne nanoparticles was also detected, by comparison with the baseline values.

- It should be noted that FSW has been pointed out as a “clean” welding process as it does not involves direct metal fusion and/or deposition. However, it still produces airborne nanoparticles.

- The highest values are obtained for hot operation instead of cold operation.

- Obtained values are higher than TIG and somewhat lower than MAG (note that TIG and MAG were tested for carbon steel and FSW for aluminum).
Further studies

- This set of measurements is the first stage of a study on airborne nanoparticles emitted in welding processes.

- The study clearly demonstrated the existence of nanoparticles in MAG and TIG welding of carbon steel, as well as in FSW of aluminum, which are clearly dependent from the distance to the welding front and also from the main welding parameters, namely the welding current.

- It should be noted that, although measured parameters such as the deposited area and the dose per lung area, are elevated when compared with baseline values, they cannot, at this stage, be ascertained as toxicity indicators.

- These preliminary measurements have to be complemented with the size distribution of airborne nanoparticles and also the chemical composition and information on the shape and crystalline nature of these particles.