Single Particle Analysis of Welding Fumes - An Investigation of a Working Environment

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Introduction

Welding produces vast amounts of particulates in the size range of ~10nm up to a few µm and above. With increasing awareness of possible adverse health effects of nanoparticles (diameter < 100nm, PM0.1) more thorough investigations of working environments are conducted. In this study we present a combination of on- and off-line measurements for an integral assessment of the particulate exposure caused by welding activities.

At the engineering business under investigation fully and semi automated micro-casting techniques are applied. Several workplaces are situated in the same building together with a central control room for the fully automated work places and a locker room. The principle process applied is gas metal arc welding (GMAW) with 97.5% Ar and 2.5% CO\textsubscript{2} on steel nr. 1.4313 (Table 1) with steel welding rods (material nr. 1.4351; Table 1).

<table>
<thead>
<tr>
<th>Material Nr.</th>
<th>Base Material</th>
<th>Welding Rod</th>
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<tbody>
<tr>
<td>Si</td>
<td>&lt; 0.70%</td>
<td>0.25% - 0.55%</td>
</tr>
<tr>
<td>Mn</td>
<td>&lt; 1.50%</td>
<td>0.55% - 0.95%</td>
</tr>
<tr>
<td>Cr</td>
<td>12.0 - 14.0%</td>
<td>12.7% - 14.8%</td>
</tr>
<tr>
<td>Mo</td>
<td>0.30% - 0.70%</td>
<td>0.35% - 0.75%</td>
</tr>
<tr>
<td>Ni</td>
<td>3.50% - 4.50%</td>
<td>3.10% - 4.90%</td>
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Table 1: Principle alloys present in the steel types used for GMAW. In addition to the elements listed traces (<0.1%) of C, P, S and N (only base material) are tolerated. The diameter of the welding rod is 1.2mm for both techniques. Base materials are cleaned and heated to ~110°C prior to welding.

Instrumentation

On-line measurements of particle size distributions and number concentrations were performed with a fast mobility particle sizer (FMPS, time resolution: 1s) TSI model 3091 and a scanning mobility particle sizer (SMPS) TSI model 3034. The time resolution of the SMPS is 3 minutes. As the variations in the particle number concentrations occurred on a smaller time scale, the air used for the SMPS measurements was drawn from a sampling bag (110 l) which homogenized the air masses. Additionally, particle number concentration was measured with high time resolution (1s) with an electrical diffusion battery (EDB).

TEM Analysis

The acquisition times of the samples for TEM analysis vary between 1 hour and 10min, depending on the sampling device and the inlet location (background, average work place, directly at the source).

As is typical for combustion and high temperature processes welding fume consists of chain-like agglomerates, fractal in appearance or clogged. Slight variations in the elemental composition of the agglomerates are observed (see poster, Figure 5). Single particle analysis on the TEM samples allowed a clear distinction types of primary particles (see poster, Figure 4) on the basis of their physical appearance. Most of the agglomerates are composed of three types of primary particles: (i) <15nm in diameter, spherical in shape and monocrystalline; (ii) 15nm - 60nm in diameter, angled and monocrystalline; (iii) >60nm in diameter, spherical in shape and crystalline.

Whether the variations in the elemental compositions of the agglomerates can be traced to classes of primary particles or not is still under investigation. Since all of the primary particles appear to be crystalline (see poster, Fig. 6) additional information on the elemental composition of the particles can be gained by examining their crystalline structure.
While the modes at 40nm and 160nm could be observed on the TEM samples, hardly any particles with diameters below 20nm were found. This fact could not yet be explained and is subject of further investigation.

Conclusions
With the combination of on-line measurements and off-line analysis methods suggested in this study, a complete data set on exposure to particulate matter for risk assessments of working environments can be compiled.

The additional information gained by electron microscopic single particle analysis renders a more thorough picture of the nature and availability of possibly harmful substances.

Acknowledgment
We thank Oliver Bischof and Jürgen Reith from TSI Europe for joining us on our measurement campaign with a FMPS and giving us the data for further analysis. This work has been supported by SILAG and the Foundation for Pneumoconiosis-Research.
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Introduction
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<th>Table 1: Principle alloys present in the steel types used for GMAW. In addition to the elements listed traces (&lt; 0.1%) of C, P, S and N (only base material) are tolerated. The diameter of the welding rod is 1.2mm for both techniques. Base materials are steamed and heated to ~110°C prior to welding.</th>
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Instrumentation
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The aerosol inlet was placed ~2m away from the welding arc (Figure 2) mirrors the passing of a fresh plume with distinct events of higher particle number concentration observed. The mode at ~160nm corresponds to welding fumes produced at this work place. The large variations in particle numbers are due to changing air currents transporting plumes of fresh welding fumes directly to the inlets of the two measuring devices – 4m from the arc of a fully automated welding robot. The large variations in particle numbers are due to changing air currents transporting plumes of fresh welding fumes directly to the inlets. The average PM0.1 number concentration is 8·10¹⁰ particles/cm³, which corresponds to a heavily frequented highway.

On-line Measurements
Bag buffered SMPS measurements of fresh welding fumes (2µm distance to the source) revealed particle modes at 20nm, 40nm and 160nm (Figure 1). FMPS measurements with high time resolution (1s) from the same inlet location showed that the mode at 20nm can only be observed inside a plume (Figure 2). The comparison with particle size distributions at background sites (>10m away from source) confirmed this interpretation.

The evolution of the particle number concentration measured at 4m distance to the welding arc (Figure 3) mirrors the passing of a fresh plume with distinct events of higher concentrations.

Conclusions
With the combination of on-line measurements and off-line analysis methods suggested in this study, a complete data set on exposure to particulate matter for risk assessments of working environments can be compiled. The additional information gained by electron microscopical single particle analysis renders a more thorough picture of the nature and availability of possibly harmful substances.

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