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 a 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 work places 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_2 on steel nr. 1.4313 (Table 1) with steel welding rods (material nr. 1.4351; Table 1).

	Base Material	*Welding Rod*
Material Nr.	1.4313	1.4351
Si	< 0.70%	0.25% - 0.55%
Mn	< 1.50%	0.55% - 0.95%
Cr	12.0 - 14.0%	12.7% - 14.8%
Mo	0.30% - 0.70%	0.35% - 0.75%
Ni	3.50% - 4.50%	3.10% - 4.90%

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).

Samples for off-line single particle analysis in a transmission electron microscope (TEM; Philips CM30, LaB_6 source) were collected directly onto microscope grids with an electrostatic and a thermophoretic sampling device.

On-Line Measurements

Bag buffered SMPS measurements of fresh welding fumes (2m distance to the source) revealed particle modes at ~20nm, 40nm and 160nm (see poster, 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 (see poster, Figure 2) and only as short bursts (approx. 2 min). 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 (see poster, Fig. 3) mirrors the passing of fresh plumes with distinct events of higher concentrations. Average PM0.5 number concentration were $8{\cdot}10^4$ particles/cm³, which corresponds to a heavily frequented highway.

Even after longer periods without welding activity (>2 hours, premises are well ventilated), the particle number concentration did not drop below $6.5{\cdot}10^4$ part./cm³ and the modes at 40nm and 160nm were still clearly distinguishable.

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.

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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

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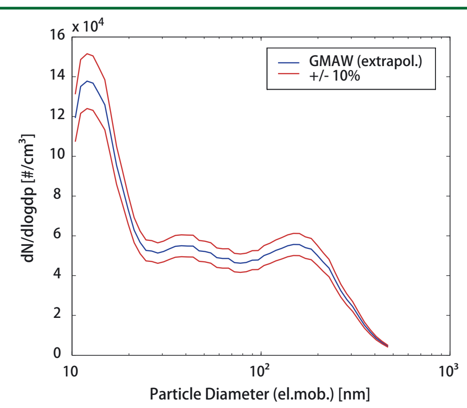

Figure 1:
Particle size distribution corrected for particle losses as calculated from a series of SMPS scans performed on an air sample delivered by a 110 litre bag sampling system. The inlet of the bag system was placed ~2m above the arc of a fully automated work place, directly in the plume of fresh welding fumes.
The size distribution shown represents a well mixed body of air sampled over a time period of 20 min.

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.

Even after longer periods without welding activity (2h, premises are well ventilated), the particle number concentration did not drop below $6.5 \cdot 10^4$ part./cm^3 and the modes at 40nm and 160nm were still clearly distinguishable.

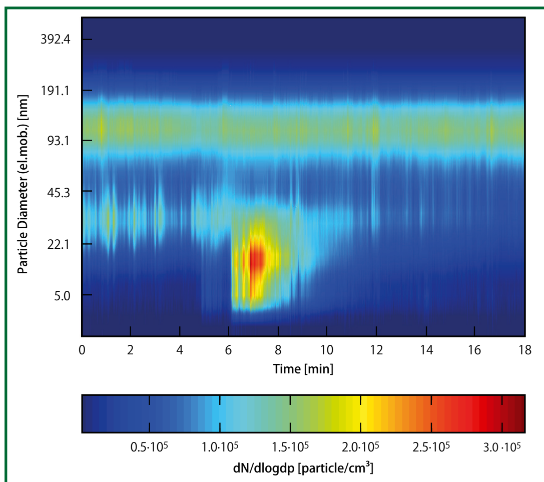

Figure 2:
FMPS scan series with 1s time resolution. The aerosol inlet was placed ~2m away from the arc of a semi automated work place. Measurements performed with this inlet position represent the normal exposition of the supervising employee to welding fumes produced at this work place.
The mode at ~160nm corresponds to the background concentration in the construction hall and consists of larger chains of primary particles. The short burst of particles with diameter ~18nm is due to a plume of newly produced particles passing the inlet.

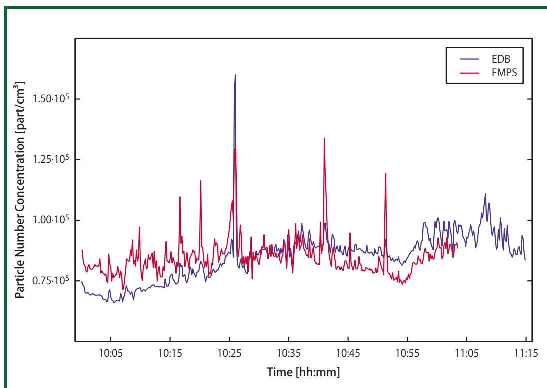

Figure 3:
Particle number concentration measured by an electrical diffusion battery and a fast mobility particle sizer. The inlets of the two measuring devices were placed ~4m from the arc of a fully automated work place. The large variations in particle numbers are due to changing air currents transporting plumes of fresh welding fumes directly to the inlets.
The average PM0.5 number concentration is $8 \cdot 10^4$ particles/cm^3, which corresponds to a heavily frequented highway.

TEM Analysis

Single particle analysis on the TEM samples allowed a clear distinction of three types of primary particles (Figure 4) on the basis of their physical appearance. Slight variations in the elemental composition of the agglomerates are observed (Figure 5). Whether these

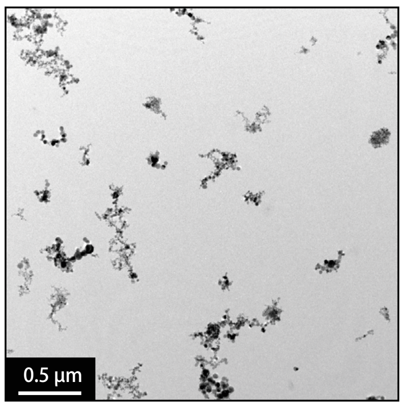

Figure 4:
Low magnification TEM image of a sample taken with the electrostatic sampling device (4m distance to the source) illustrating the different particle shapes observed.
Most of the agglomerates are composed of three types of primary particles:
(i) <15nm in diameter, spherical in shape & monocrystalline;
(ii) 15nm - 60nm in diameter, angled & monocrystalline;
(iii) >60nm in diameter, spherical in shape & crystalline.

variations can be traced to classes of primary particles or not is still under investigation. Since all of the primary particles appear to be crystalline (Figure 6) additional information on the elemental composition of the particles can be gained by examining their crystalline structure.

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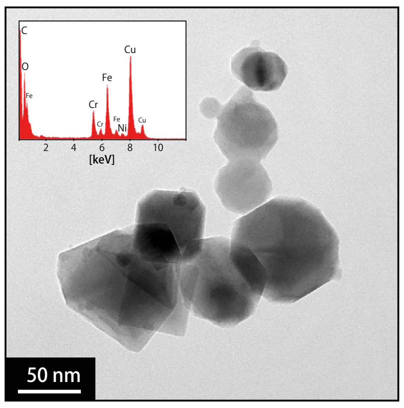

Figure 5:
TEM micrograph of a typical particle of intermediate size (mode at 160nm). The inlay shows the result of the energy dispersive x-ray analysis. The C and Cu peaks are produced by the TEM grid and the grid holder and not by the particle. Comparing EDX spectra of various particles, the Fe/Cr peak ratio varies from 2/1 to 4/1 and the Cr/Ni peak ratio stays around 3/1.

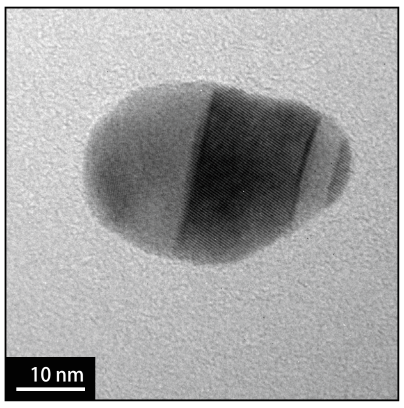

Figure 6:
High magnification image of an individual (twinned) particle. Such particles together with small agglomerates of primary particles with diameter below 15nm contribute most to the mode at 40nm (see Fig. 1 & 2).

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.

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