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Characteristics of Welding Fume Aerosol Investigated in Three Swedish Workshops

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Abstract: Potentially high human exposures to nanometer sized airborne particles occur due to welding and other thermal processes in industrial environments. Detailed field measurements of physical and chemical particle characteristics were performed in three work-shops in Sweden. Measurements were performed both in the plume 5-20 cm above the welding point and in the background air (more than 5 m away from the nearest known particle source). Particle number and mass concentrations were measured on-line. A low pressure impactor was used for size-resolved chemical particle composition. The in-plume measurements generated the chemical signatures for different welding processes. These signatures were then used to identify contributions from various processes to the particle concentrations in different size classes. The background number and mass concentrations increased by more than an order of magnitude during intense activities in the work-shops compared to low activities during breaks.

1. Introduction

In industrial environments nano sized particles occur at much higher concentrations than in ambient and indoor air. Welding is one of the more important sources for fine and ultrafine particles in industrial environments worldwide. Only in the United States there are nearly 0.5 million people performing welding and cutting operations full-time, and additional 1-2 million workers who weld intermittently [1]. The total amount of smoke emitted from the welding industry is estimated to 5000 tons/year [2]. Particles from welding processes are enriched in metals, which from a health perspective makes the study even more relevant.

The focus of our project is mild-steel welding, particularly Gas Metal Arc Welding (GMAW), since it is one of the most frequently used indoor welding methods. This method is often referred to as Metal Inert Gas (MIG) or Metal Active Gas (MAG), depending on the composition of the shielding gas. The gas is used for protecting the molten metal from oxidation by creating a microclimate around the welding point, thus shielding it from the oxygen in the surrounding atmosphere. The choice of shielding gas depends on the substrate; however a welding process is often optimized by using a mixture of the two types of gases. Also the composition of the electrode is substrate dependent, so that a welding joint with mechanical properties similar to the substrate is obtained.

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It has been shown that the fume composition is reasonably independent of the substrate material itself and that the welding fume is mainly composed by species from the electrode material [3]. The substrate only seems to influence the fume composition if covered with oil, paint or any similar substance [4].

The aim of this study is to determine detailed emission characteristics of welding aerosols in three welding workshops in southern Sweden to improve the knowledge of nanoparticle exposure, particularly to welding fumes in real-world work-places. This knowledge will also be used to generate relevant welding fume for controlled human chamber exposures in the laboratory at Ergonomics and Aerosol Technology at Lund University.

2. Methods

Workshop 1 produces wind mills and railway wagons, and resides in the spacious open halls of a former shipyard. Workshop 2 is placed in a foundry, where several activities other than welding takes place, such as carbon arc gouging, chiseling and grinding. In the third workshop the main activity is welding, only interrupted by a few other operations where the welding joints are being smoothed.

Samples were taken at two different points in each of the three workshops. The first sampling point was at 2 m height, at least 5 m distance from the nearest known source of fine and ultrafine particles, using a PM10 inlet. The purpose of this was to sample the workshop background air. The second sampling point was in a freshly generated welding plume at a distance 5-20 cm above the welding point using a sampling probe immediately connected to a two stage ejector dilution system, which provided a fume dilution factor of 1:150. The dilution probe was introduced to reduce the magnitude of aerosol dynamics processes, particularly coagulation and to cool and dilute the sample to the range of the measurement systems. The in-plume measurements provided the signature size distribution and composition of welding fumes.

The total sampled airflow of 16.7 lpm was led to a flow splitter which distributed the flow to the different instruments, which were as follows: fine and ultrafine particle size distributions were determined using a Scanning Mobility Particle Sizer (SMPS, 10-1000 nm, time resolution of several minutes) and a Fast Mobility Particle Sizer (FMPS, 5-560 nm, 1 s time-resolution), coarse particle number size distributions were determined with an Aerodynamic Particle Sizer (APS, 0.5-20 um). The PM_{10} mass concentration was determined using a Tapered Element Oscillating Microbalance (TEOM), the results of this instrument were compared to a photometer (DustTrak). The lung deposited surface area concentration was determined using a Nanoparticle Surface Area Monitor (NSAM). Two low pressure impactors (LPI) were used, a Hering LPI for collecting samples for Transmission Electron Microscopy (TEM) and a Dekati LPI to collect size-segregated samples (13 stages, 30-10000 nm) for chemical analysis using Particle Induced X-ray Emission (PIXE). To estimate personal particle exposure, selected welders carried personal filter samplers incorporating respirable fraction cyclone pre-collectors. Relative humidity and temperature were also monitored.

3. Results and discussions

3.1. Number- and mass concentrations

A representative sample of the large time-fluctuations in the background measurements are shown in figure 1 for total number concentration (15-1000 nm) and for PM10 mass concentration. It can be seen that the activities increase the exposure both in terms of number and mass by more than an order of magnitude, compared to the level during breaks. A clear correlation between increases in number and mass could be found. The PM_{10} measurements in the "background" zone ranged from < 100 $\mu g/m^3$ during longer breaks up to 3000 $\mu g/m^3$ during intense activities. Correlations between PM_{10} determined with the TEOM and the photometer are being investigated. Personal exposures measured as respirable dust ranged from 600-3400 $\mu g/m^3$.

From the in-plume measurements the signature number size distributions from welding could be determined and typically yielded a single mode with geometric mean diameter of 100-150 nm. It was found that the high time resolution of the FMPS instrument was a clear advantage compared to the SMPS in these measurements with strong concentration fluctuations over time (not shown).

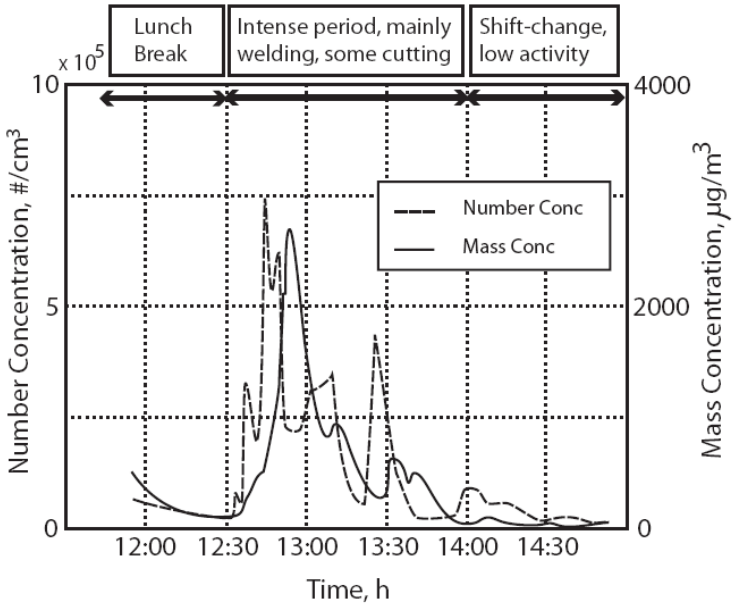

Figure 1. Number concentrations measured with SMPS and mass concentration measured as PM10 with the TEOM at the background measurement point during the afternoon at workshop 3.

3.2. Mass size distributions and chemical composition

Normalized mass size distributions based on the elements detected with PIXE are given in figure 2 for the in-plume measurements and in figure 3 for the background measurements. It can be seen that the signature size distributions of MAG-welding appears as a single mode with mass median aerodynamic diameter (MMAD) of 200-300 nm, while the experiment with stick welding generated larger particles. The stick electrodes used (Elga, Maxeta 22, 6 x 600 mm) were of high output type. They were used to generate filling in larger cracks (5-10 cm) in the components being manufactured.

The elemental composition as a function of particle size was calculated for health relevant and major elements. In figure 4, an example is given for in-plume measurements of MAG-welding in mild steel. The particle composition is dominated by Iron, while the Manganese fraction increases with size. This suggests that Manganese condenses onto existing particles at lower temperatures in the formation process. Further, the fraction of Nickel and Chromium is very low, as expected for welding in mild steel.

In figure 5, a sample of the background air in the same workshop is given. It can be seen that the fraction of Ni and Cr is about an order of magnitude higher compared to the mild steel welding signature in figure 4. This indicates the presence of work in stainless steel within the workshop. The fraction of these compounds is strongly elevated for particles smaller than 150 nm. This either reflects that welding in stainless steel generates smaller particles, or that another operation in stainless steel, for example cutting is dominating in this size range. In the size-range between 150 and 500 nm, the fractions of Fe and Mn are in the same range as in figure 4 and the Ni and Cr concentrations are low. This suggests that MAG welding in mild steel is the main source for these sizes. In the background measurement, the fraction of Mn decreases towards a few percent for coarse particles, which is in the same range as the raw material (mild steel). This would be expected for an aerosol being generated by

mechanical processes, in contrast to the evaporation-condensation processes which are responsible for the fine mode. Further, the fractions of Ni and Cr increases with increasing particle size above 300 nm. This indicates the presence of mechanical processes in stainless steel as well.

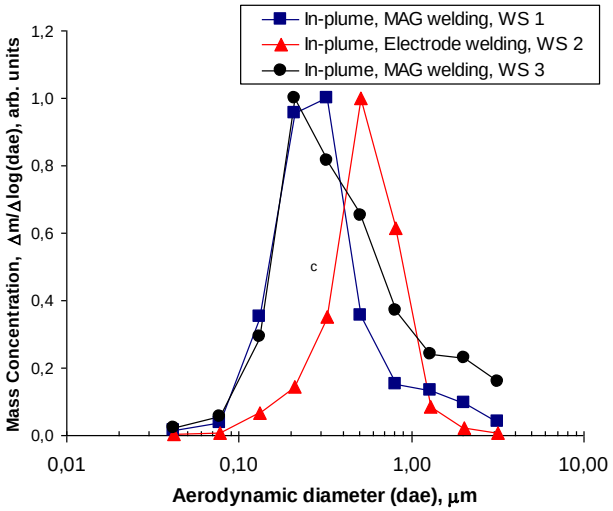

Figure 2. Normalized mass size distributions from in-plume measurements in work shops.

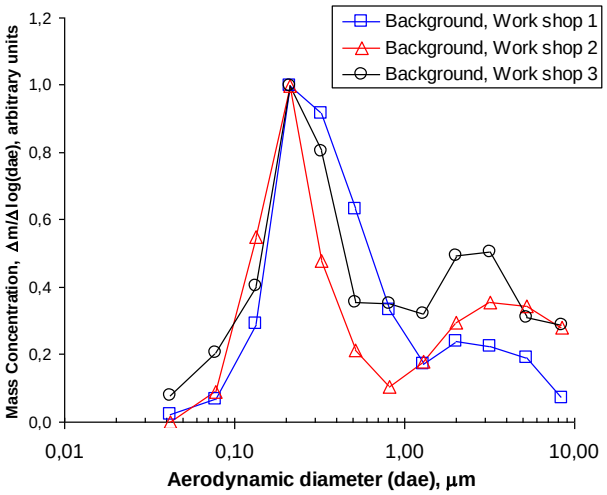

Figure 3. Normalized mass size distributions from background measurements in work shops

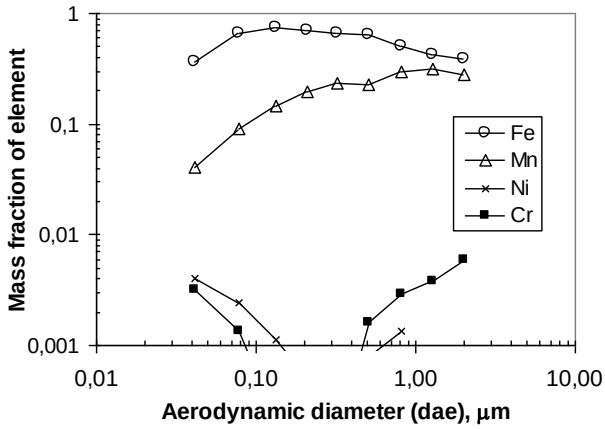

Figure 4. Size-fractionated elemental composition of welding fumes from an in-plume measurement in workshop 3, MAG-welding in mild steel.

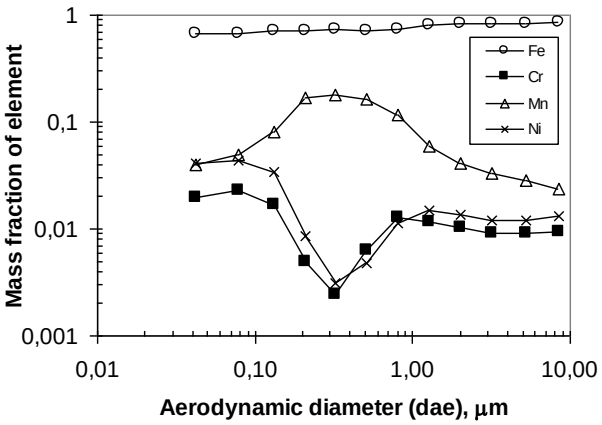

Figure 5. Size-fractionated elemental composition of particles sampled during a background measurement in workshop 3.

4. Conclusions

Using a large range of aerosol measurement techniques, representing the state of the art, exposure levels and particles characteristics have been identified in field measurements in real work environments. Further the combination of techniques can be used to identify detailed knowledge of the contributions from separate sources to the airborne particle concentrations.

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