Characterization of Nanoparticles Produced from a Spark Discharge System with Manganese and Iron Alloy Electrodes

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Abstract

Welding fumes typically consist of high concentrations of metallic particles smaller than 300 nm. The small particle size and presence of metals, such as manganese (Mn), contribute to the toxicity of welding fumes. Mn nanoparticle exposure from welding fumes is associated with slower reaction time, hand tremors, and Parkinson's disease-like symptoms, referred to as manganism. To evaluate the toxicity of welding fumes in the lab, a welding fume generation system is required. The ability to control welding fume concentrations is critical in toxicological studies. Only a few welding fume inhalation exposure systems have been developed due to the numerous different types of welding processes employed in the workplace, and the difficulties with generating a fume with stable output over extended periods. Recently, a spark discharge system (SDS) has been used to simulate the welding fumes. In this study, Mn and Iron (Fe) electrodes were used to simulate welding fumes in the SDS. Various electrodes were used to simulate different metal contents and particle size distributions. The results indicate a significant trend in higher Mn content electrodes producing larger-sized particles at a higher generation rate in comparison to higher Fe content electrodes.

Introduction

Welding Fumes

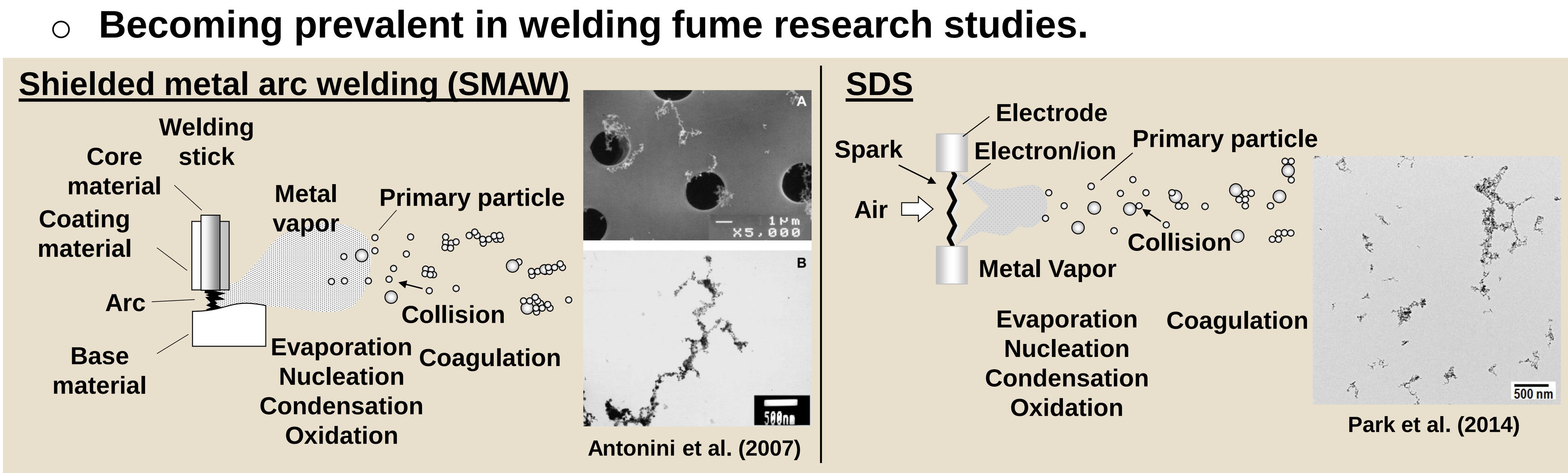
- Mixture of particulates and gases containing hazardous metals such as manganese (Mn) and Chromium (Cr).
- Metals produce chronic and acute adverse health effects such as metal fume fever, cardiopulmonary issues, lung diseases, etc.
- Size of particles in welding fumes
  - 0.005 – 20 μm, large proportion fine (<2.0 μm) and nano (<100 nm) particles
  - Nanoparticles can known to be more toxic than larger-sized particles.
  - Nanoparticles deposit deeper in the lungs, and translocate to other organs.

Mn in Welding Fumes

- Major source of Mn exposure in occupational settings.
- Associated with slower reaction time, hand tremor, and Parkison-like disease.
  - These negative health effects are referred to as Manganism.
- Mn content in welding fumes varies.
  - Up to 10% of mass can be attributed to Mn.

Welding Fume Generation in the Lab

- Conventional Methods
  - Experienced welders generate fumes → Researchers collect fumes → Re-aerosolize the fumes in toxicological studies
  - Automation: rotating cylinder, robot welder, etc.
  - Large area needed, costly, time consuming, and achieving stable/continuous output is difficult or impossible.
- Spark Discharge System (SDS)
  - Lab-based system for simulating welding fumes.
  - Cost effective, timely, and continuous/stable output is easily achievable.
  - Becoming prevalent in welding fume research studies.



Hypothesis

- Electrodes with varying manganese content affect the particle size distribution of the metal fumes produced.

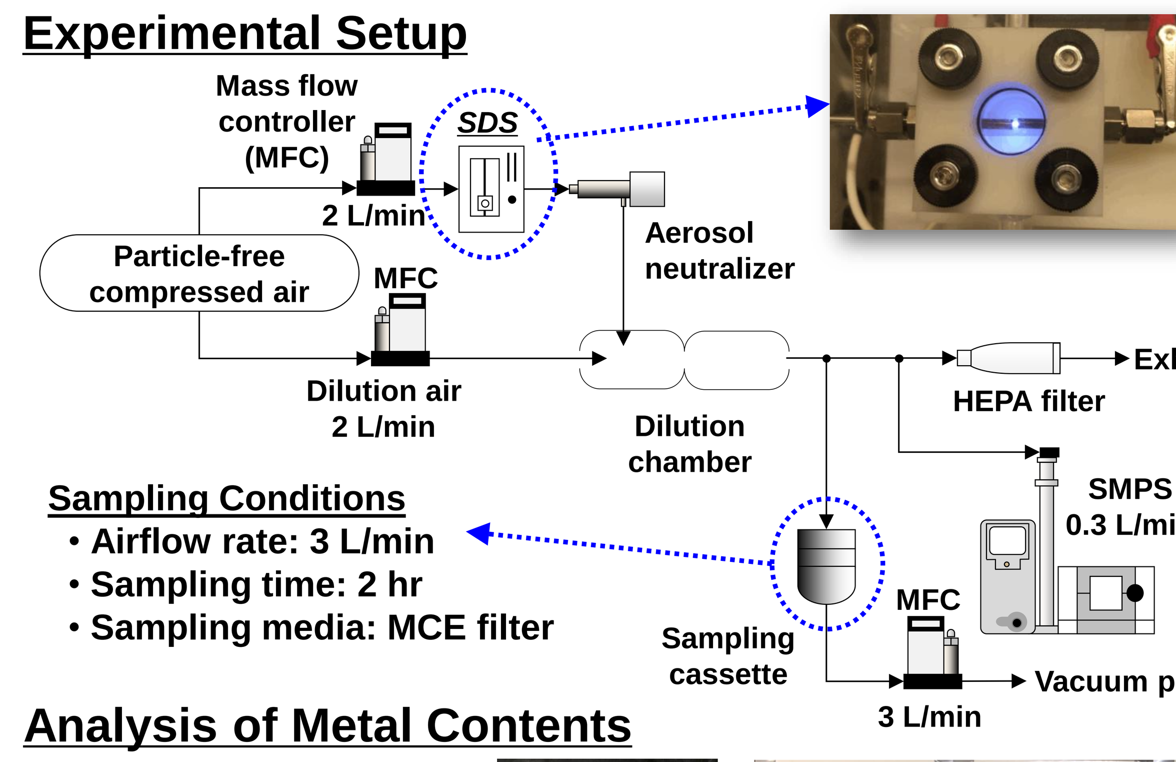
Objectives

- Real-time measurement of welding fume's size and number concentration using a scanning mobility particle sizer.
- Analysis of metal contents in electrodes and welding fumes using a field-portable X-ray fluorescence (XRF) analyzer.

Methods

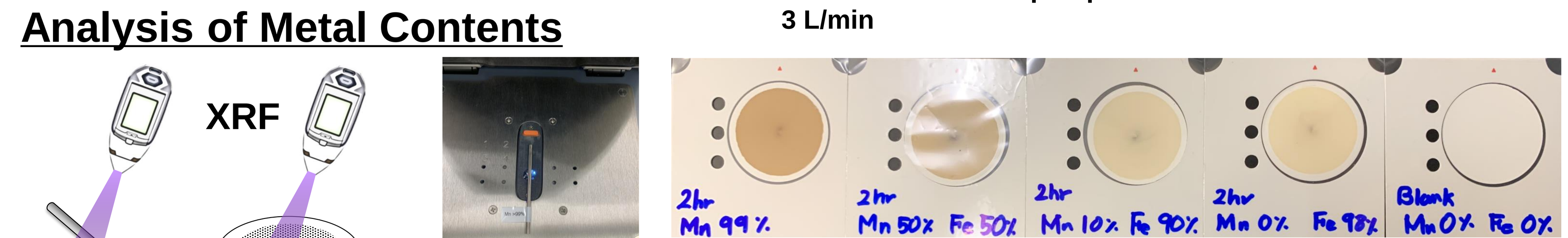
- The SDS was used to simulate the nanoparticles in the welding fumes.
- Separate experiments were conducted for electrodes consisting of pure iron (Fe), 90% Fe + 10% Mn, 50 % Fe + 50% Mn, and pure Mn.
- A scanning mobility particle sizer (SMPS) was used to obtain the total number concentrations and geometric mean diameters, creating a particle size distribution.
- The particles were collected on a mixed cellulose ester (MCE) filter at a flow rate of 3 L/min, which were later analyzed using X-ray Fluorescence (XRF; NitonTM XL3t, Thermo Fisher Scientific) to confirm the metal contents of the welding fumes.

Experimental Setup



Operational Conditions of SDS
- Applied voltage: 5 kV
- Loading current: 0.5 mA
- Electrodes
  - Pure Fe
  - Fe 90% + Mn 10%
  - Fe 50% + Mn 50%
  - Pure Mn

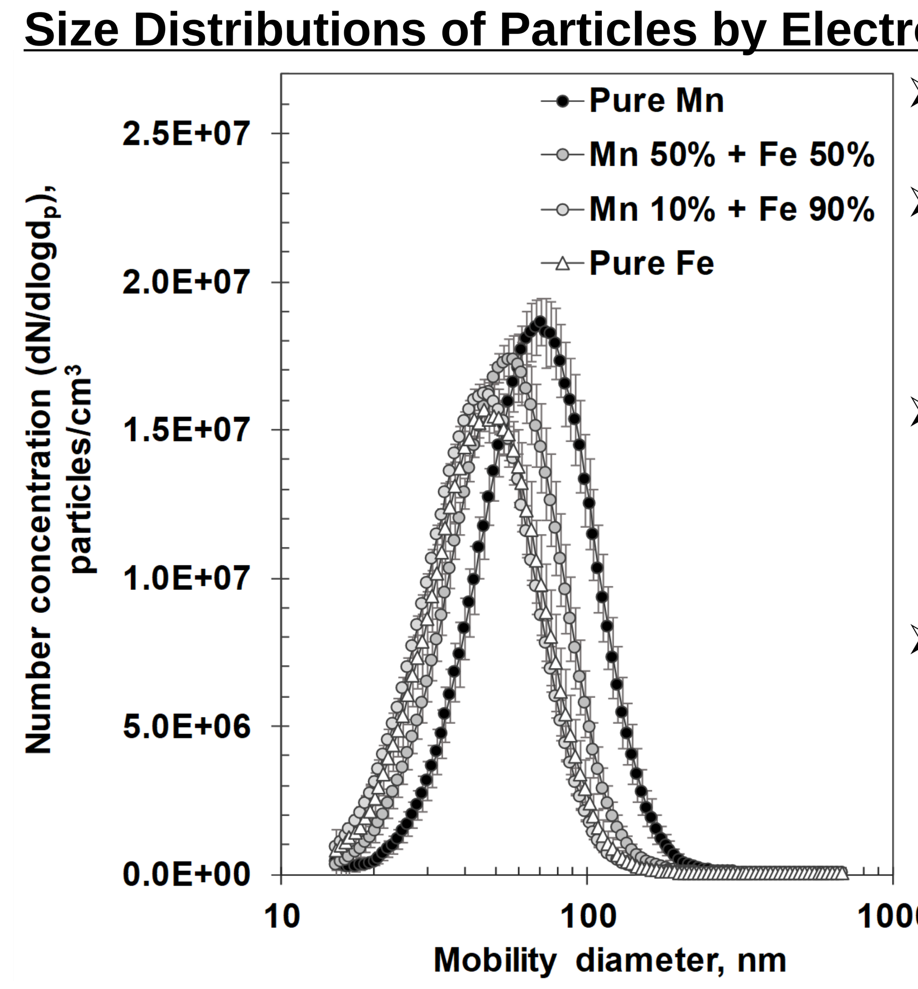
Analysis of Metal Contents



Electrode | Filter | FP-XRF loading tray with electrode | Particles collected on MCE filters

Results and Discussion

Size Distributions of Particles by Electrodes



- Nanoparticles were successfully produced in all cases.
- Size distributions of particles were log-normally distributed and the geometric standard deviations were approximately 1.5.
- Particles produced using pure Mn electrodes has:
  - Highest total number concentration
  - Largest geometric mean diameter
- Mn concentration in electrodes increased particle size and concentration.
  - Melting point at 1 atm: Mn 1246°C < Fe 1538°C
  - Initial concentration ↑ → coagulation ↑ → size ↑

Statistics of Size Distributions

	Pure Fe	Fe90% + Mn10%	Fe50% + Mn50%	Pure Mn
Total number concentration, particles/cm³	$7.13\times10^6 \pm 2.12\times10^5$	$7.30\times10^6 \pm 2.55\times10^5$	$7.79\times10^6 \pm 3.75\times10^5$	$8.60\times10^6 \pm 3.76\times10^5$
Geometric mean diameter, nm	46.3 ± 2.9	44.1 ± 0.9	52.9 ± 2.01	67.4 ± 3.1
Geometric standard deviation	1.52 ± 0.01	1.51 ± 0.01	1.52 ± 0.02	1.54 ± 0.02

Metal Contents in Electrodes and Particles

	Pure Fe	Fe90% + Mn10%	Fe50% + Mn50%	Pure Mn
Fe: Mn in electrodes	99.07 : 0.93	90.07 : 9.93	49.20 : 50.80	0 : 100
Metal contents, μg	Fe: 102.28 Mn: N.D.	Fe: 92.00 Mn: 10.77	Fe: 97.37 Mn: 105.11	Fe: N.D. Mn: 208.45
Metal concentration, μg/m³	Fe: 284.11 Mn: 0	Fe: 255.56 Mn: 29.92	Fe: 270.47 Mn: 291.97	Fe: 0 Mn: 579.03
Fe : Mn in particles	100 : 0	89.52 : 10.48	48.09 : 51.91	0 : 100
Generation rate, μg/min	0.85	0.86	1.69	1.74

Conclusions

- Generated metal contents are correlated with the relative concentrations in electrodes.
- Higher Mn content produces higher particle concentration, geometric mean diameter, and generation rate.
- Future directions include:
  - Further analysis of particle shape using a transmission electron microscopy.
  - Test with the electrodes consisting of multiple metals (e.g., Fe80% + Cu15% + Mn5%).
  - Toxicology studies.

References

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Acknowledgements

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