

Bridging Aerosol Science and Welding: Profiling of Weld Fumes Across GMAW Metal Transfer Modes



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Goal and objective

Goal: This work presents an investigation into the production of weld fumes from different GMAW metal transfer modes as a first step in a broader project aimed at understanding the physical mechanisms of weld fume generation.

Objective: As a primary objective, this work aims to correlate the GMAW metal transfer mode to particle size distribution and aggregate morphology.

Background: Why particle size matters

Known effects of fumes

- The major driving factor behind weld fume location and deposition efficiency in humans depends on particle size, morphology, density.
- Inhaled particles of critical size range can spread throughout the body by entering circulatory system via absorption in the alveolar ducts. Particles may also travel:
 - through the nose to the brain
 - to the stomach via entrapment in nasal mucus

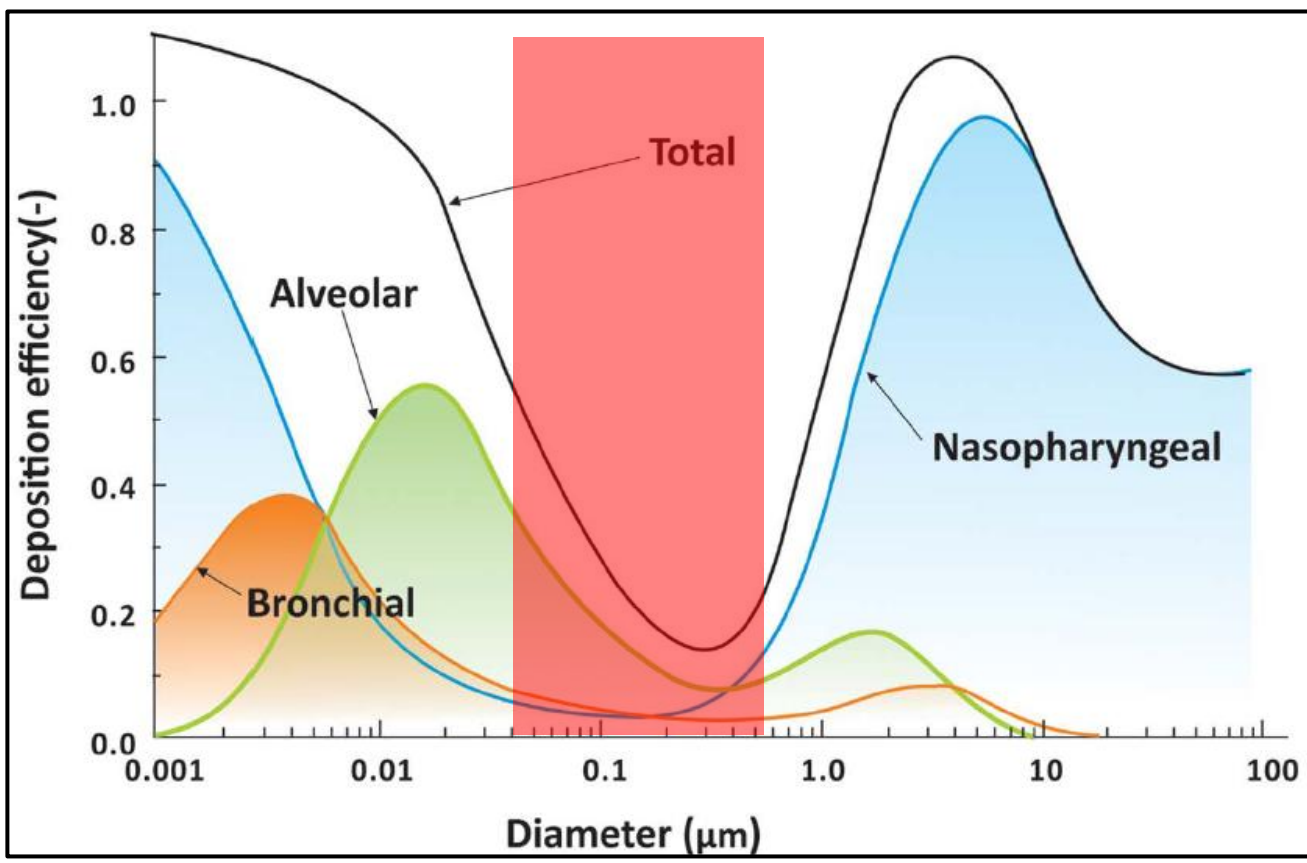


Fig 1. Particle deposition efficiency based on human body airways and diameter (Adapted from Wang et al. , 2021)

Designing engineering controls for fumes

- Engineering controls and PPE must be tailored at least to the size range of particles
- Filtration mechanisms (interception, impaction and diffusion) depends on particles sizes

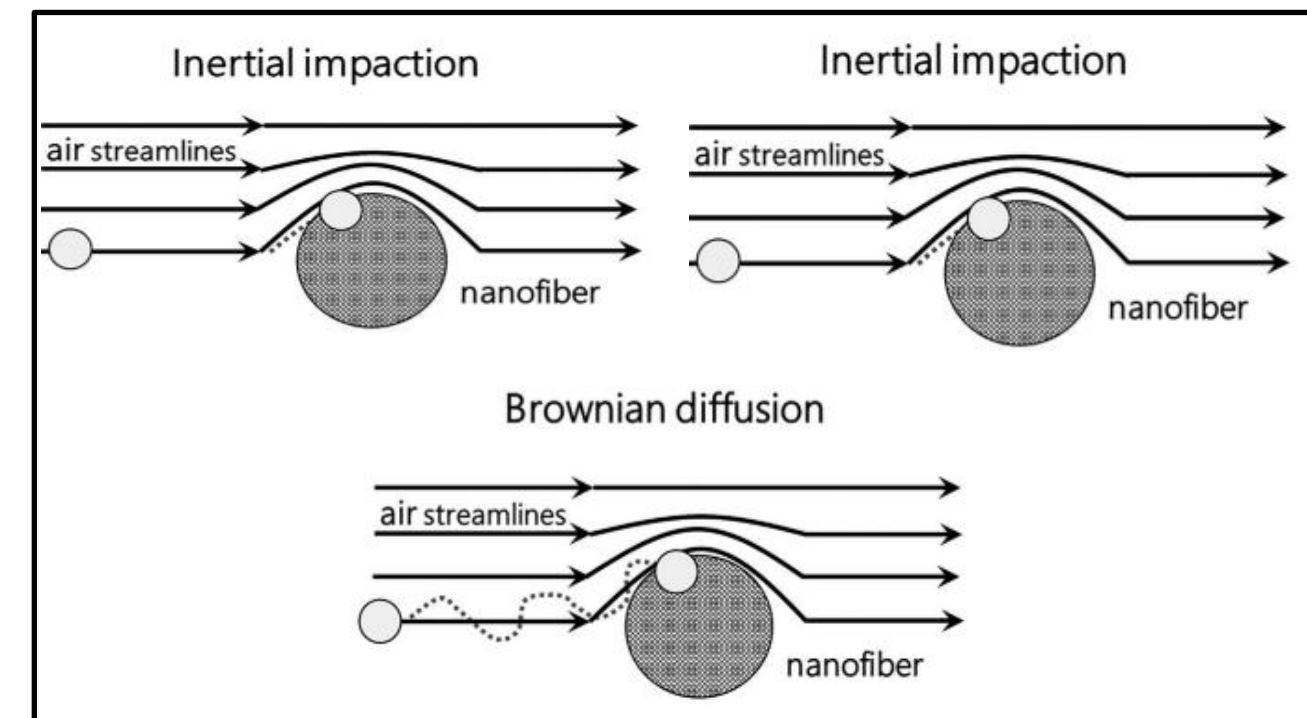


Fig 2. Filtration mechanisms based on particle size (Adapted from Russo et al., 2022))

Quantifying particle size: mobility diameter

- Mobility Equivalent Diameter (d_m): the diameter of a spherical particle that moves at same velocity through an electric field as an particle of irregular geometry. d_m determines how particles deposit, how you filter it and how it transport.
- Diffusion depends on the mobility diameter.

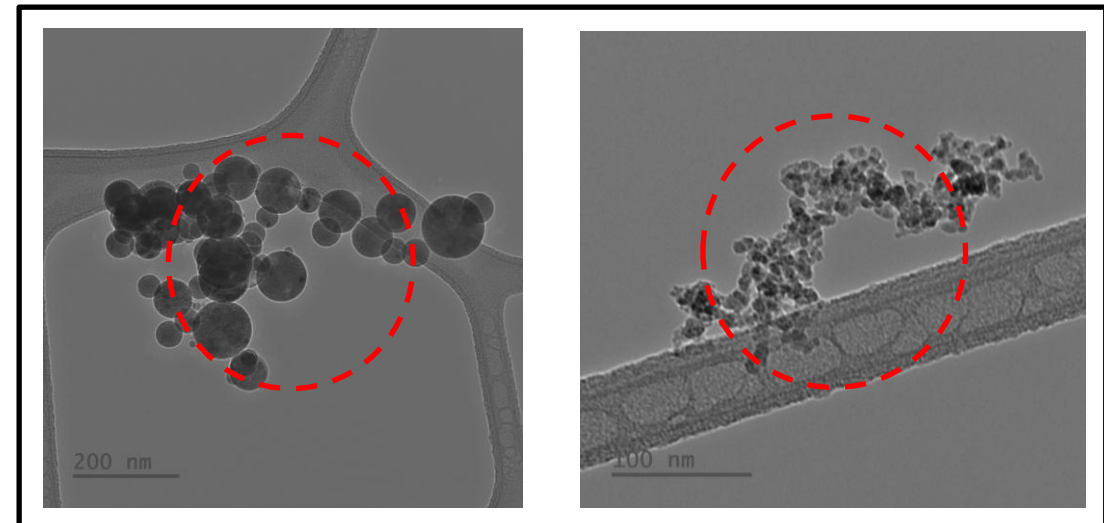


Fig 3. Schematic of Weld fume Mobility Diameter, d_m

Materials and Methods

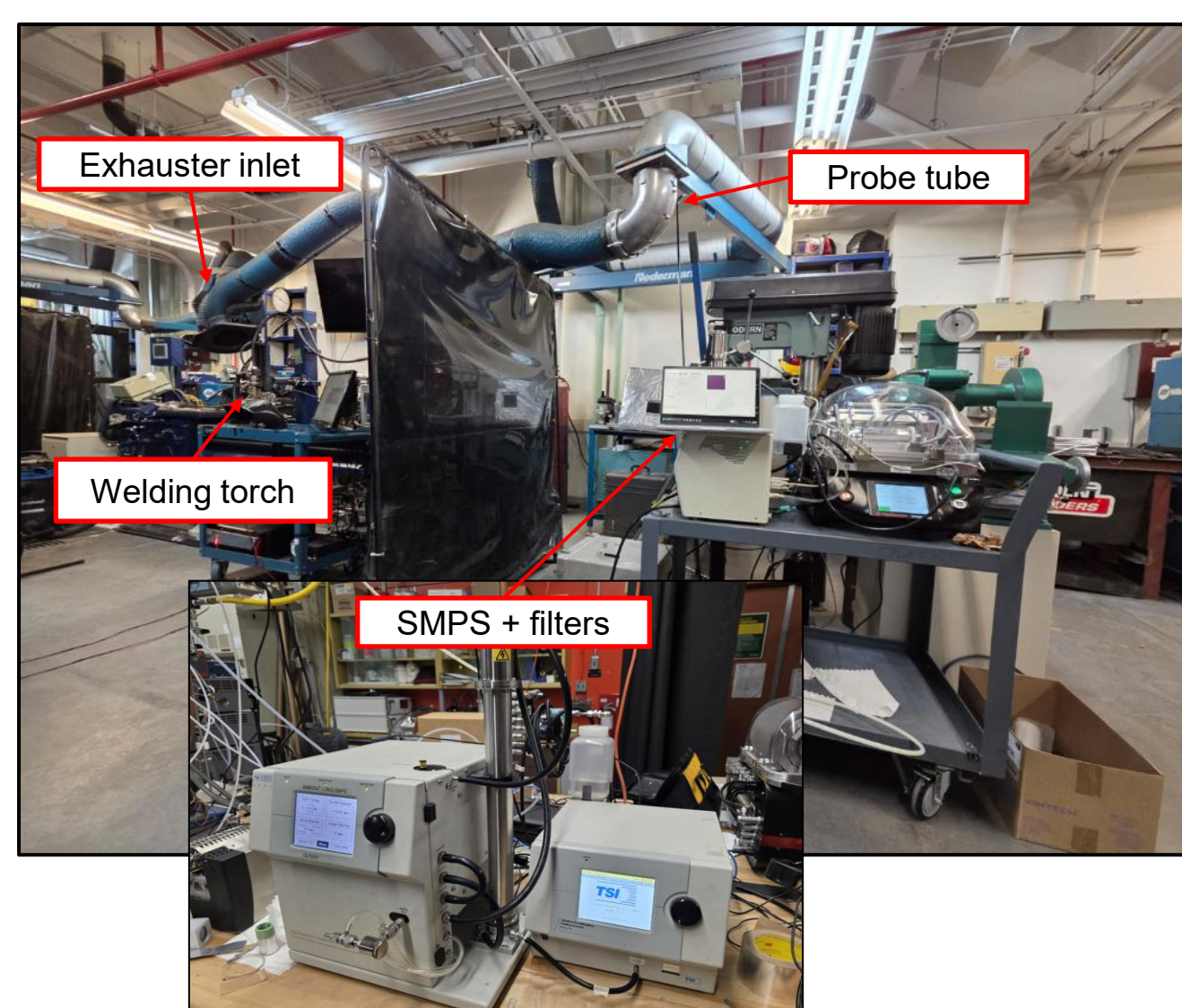


Fig 4. Experimental apparatus.

Materials and equipment

Power source: Miller PipePro 450 RFC
Filler metal: ER70S-6, ϕ 1.2 mm
Shielding gas: 85% Ar + 15% CO₂ (C15)
Base metal: ASME A36 low carbon steel plates
SMPS: TSI Inc. Electrostatic Classifier 3080 with 3081 Differential Mobility Analyzer (DMA) and 3088 neutralizer, Ultrafine Condensation Particle Counter 3776

Weld fumes from GMAW of carbon steel wire onto carbon steel plate were extracted and segregated to two sampling methods:

1. Size distribution using a Scanning Mobility Particle Sizer (SMPS)
2. Particle morphology using Scanning Electron Microscopy (SEM)

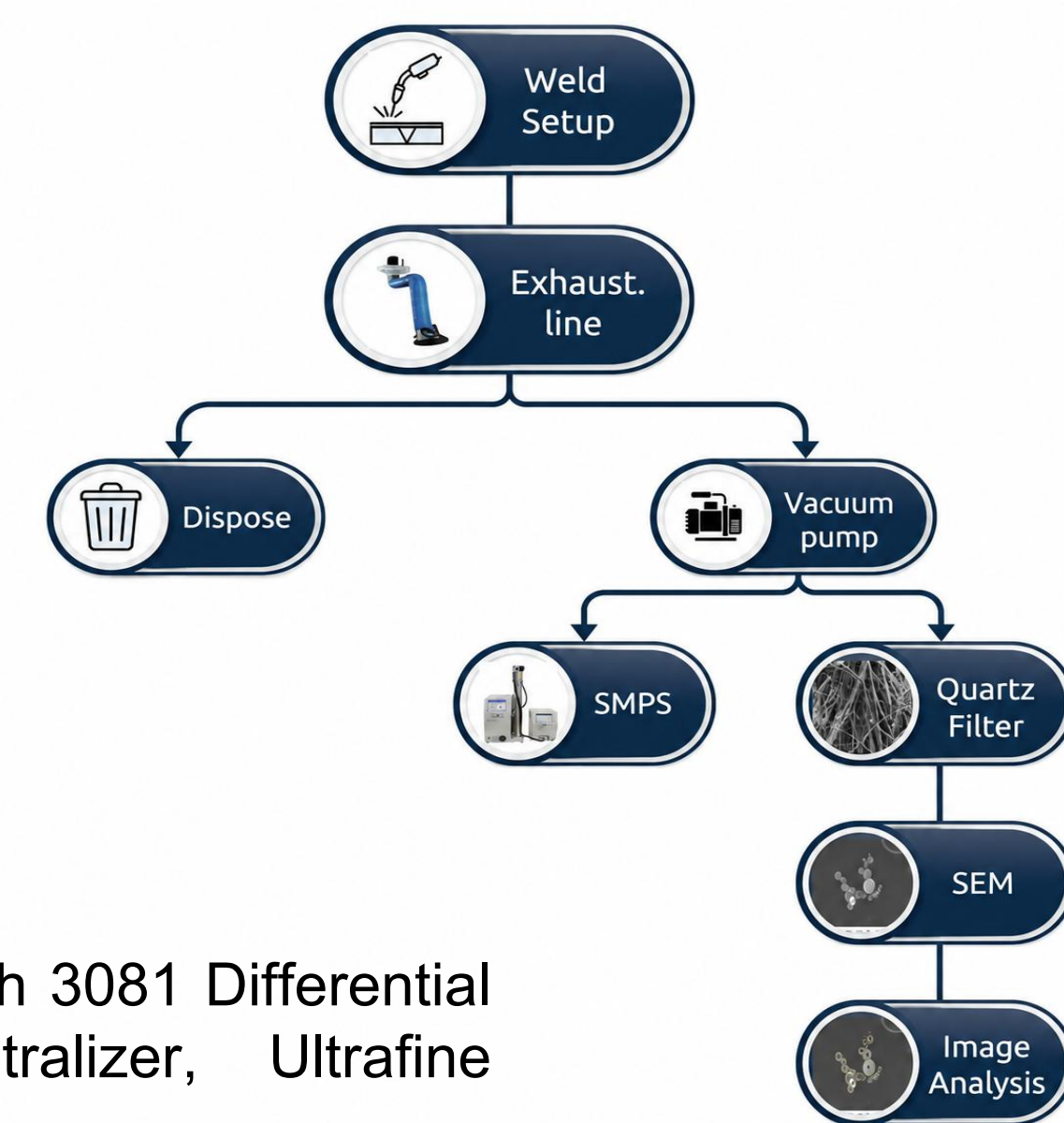


Fig 5. Sample collection methodology.

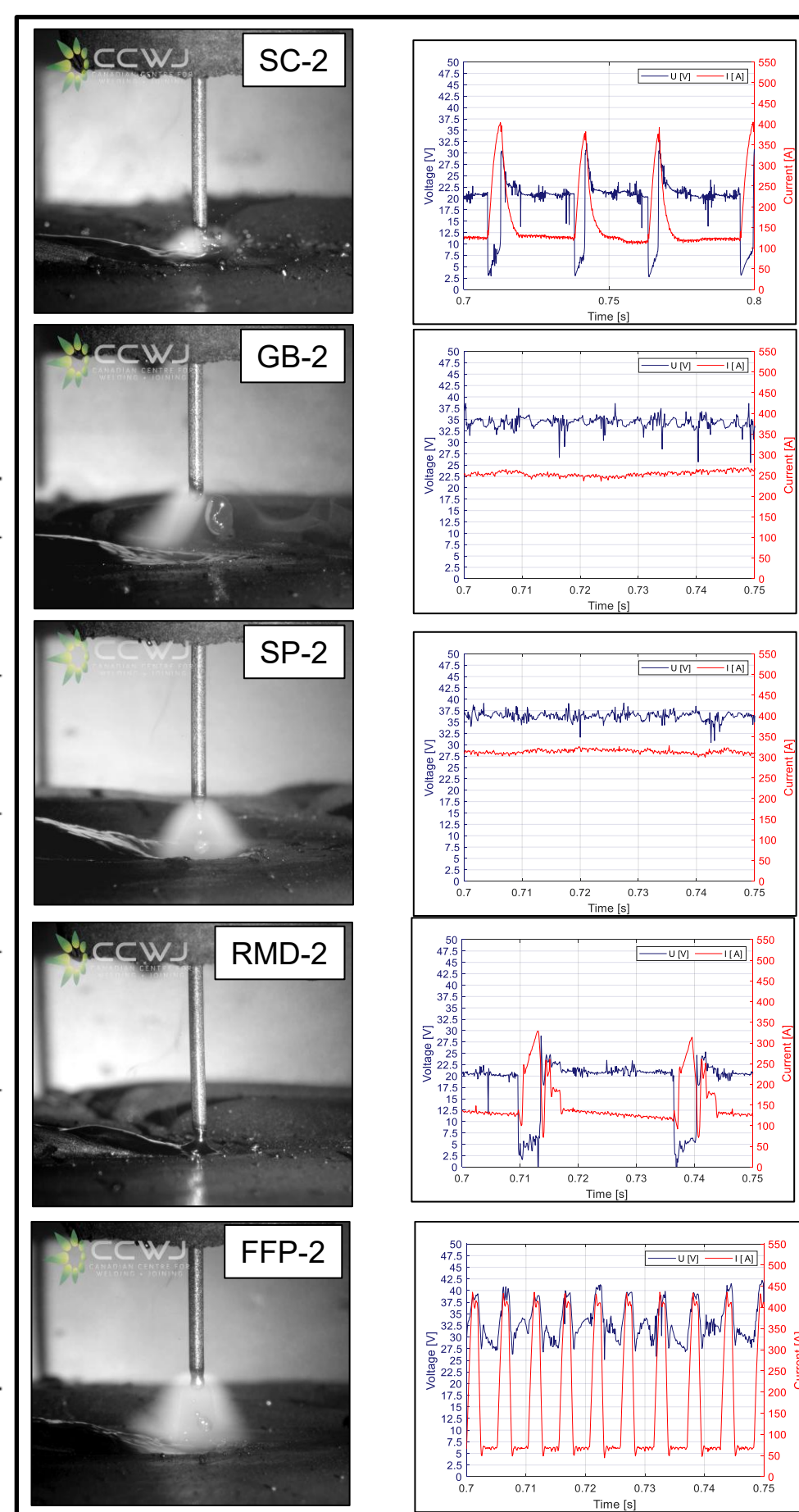
Experimental Matrix

- A dedicated experimental matrix was designed to collect fumes under different GMAW metal transfer modes and parameters within each transfer mode, on multiple days of collection to account for operational variability

Table 1. Exp. Matrix. Highlighted experiments used for SEM analysis.

Metal transfer mode	Experiment	Wire feed speed (m/min)	Arc voltage* (V)
Short Circuit	SC-1	3.8	18
	SC-2	4.4	19
	SC-3	5.1	20
Globular	GB-1	6.4	32
	GB-2	7.0	33
	GB-3	7.6	34
Spray	SP-1	9.5	34
	SP-2	10.1	35
	SP-3	10.8	36
Short Circuit - RMD	RMD-1	3.3	7
	RMD-2	3.8	7
	RMD-3	4.4	7
Free-flight - Pulsed	FFP-1	5.1	8.5
	FFP-2	5.8	8.5
	FFP-3	7.1	8.5
	FFP-4	8.9	8.5
	FFP-5	10.2	9
	FFP-6	10.7	9
	FFP-7	11.4	9

Fig 6. Voltage and current oscillograms and High-speed video frames taken from experiments ID SC-2, GB-2, SP-2, RMD-2 and FFP-5.



Results

Particles Size Distribution

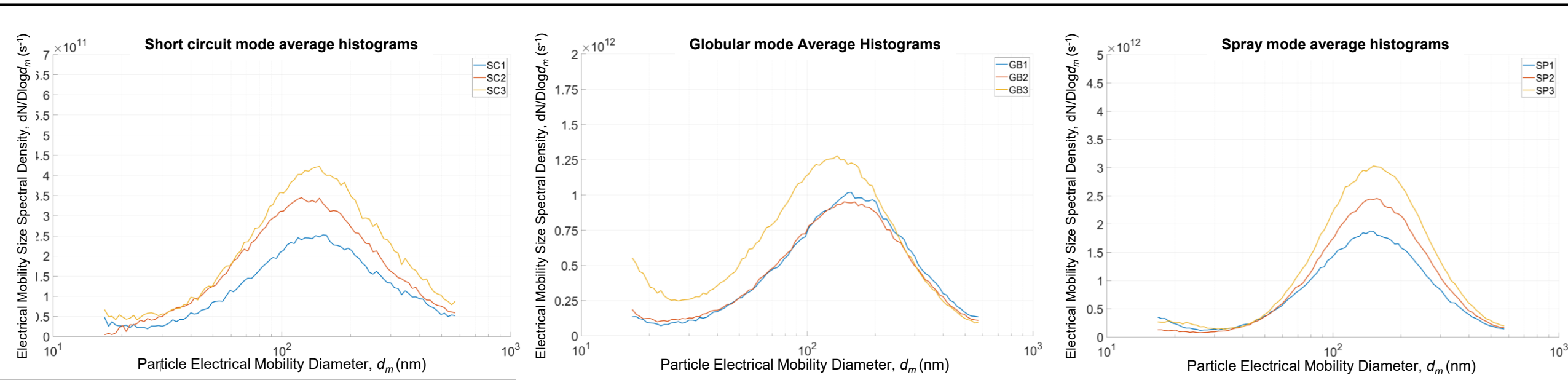


Fig 7. Particle size distribution: average of three trials of each tested condition (Short circuit, Globular, Spray, RMD and Free-flight pulsed current).

Table 2. Average Count Median Diameter (CMD) of three trials from each tested condition.

Count Median Diameter (nm)	1	2	3	4	5	6	7
RMD	115.00	109.81	113.72	-	-	-	-
SC	139.74	130.87	137.97	-	-	-	-
Glob.	150.60	143.51	124.43	-	-	-	-
Spray	145.13	149.37	150.98	-	-	-	-
FFPC	103.05	93.50	90.83	101.77	112.81	108.98	112.72

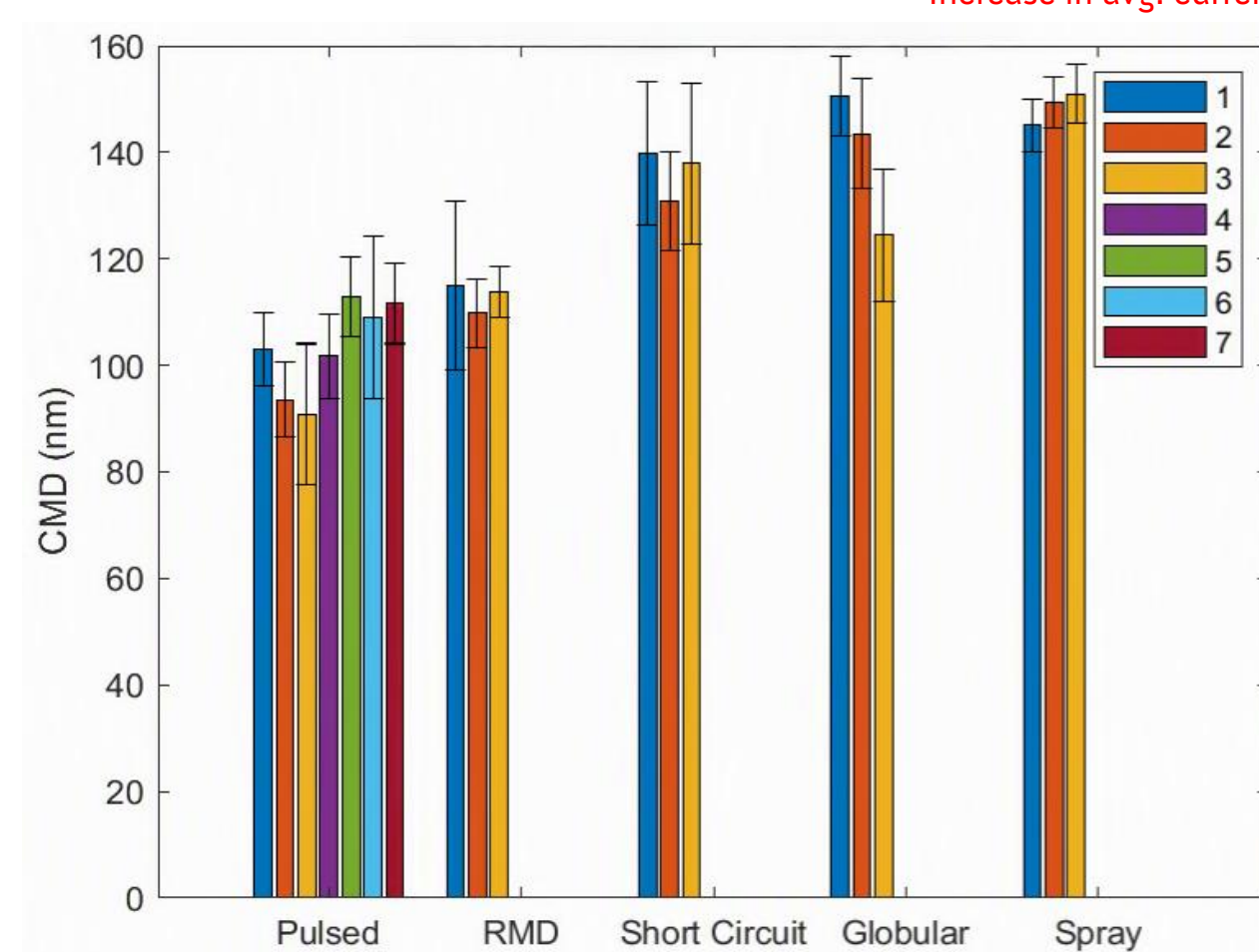


Fig 8. Average Count Median Diameter (CMD) of three trials from each tested condition.

Aggregates morphology

- Welding fumes are a collection of **aggregate particles (APs)**, which are comprised of smaller **primary particles (PPs)**.

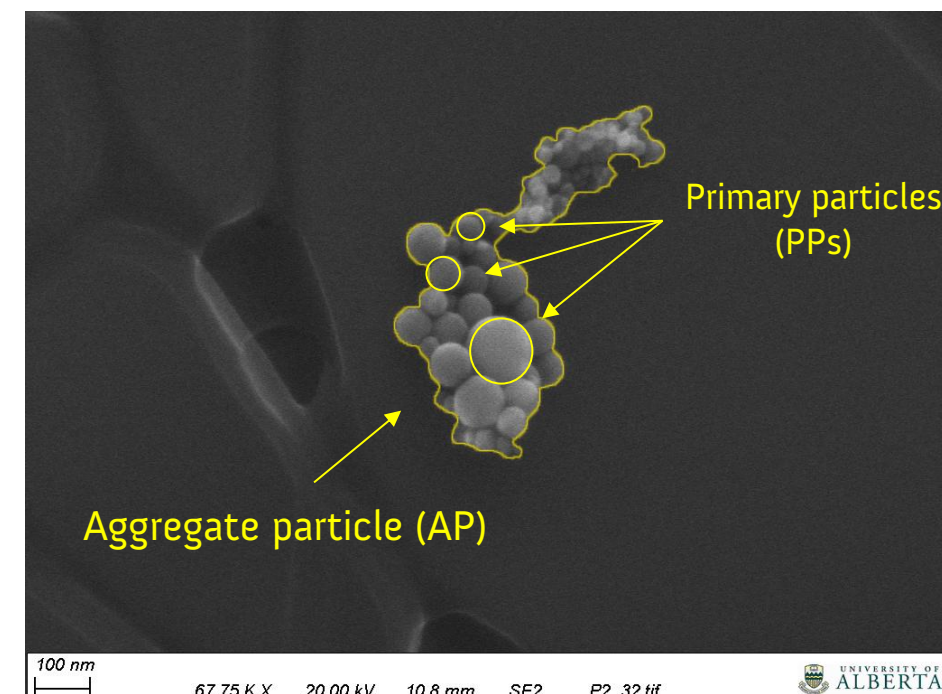


Fig 9. Example of weld fume aggregate.

- For each agglomerate, the maximum possible number of particles were considered (resolution and sharpness limitation). Total of 217 aggregates and 5274 PP's were measured within the selected experiments (experimental matrix – table 1).

Table 3. Geometrical Mean Diameter (GMD) and Geometrical Standard Deviation (GSD) within measured aggregates

Metal transfer mode	GMD (nm)	GSD	Min and Max GMD (nm)	Min and Max PP diameter (nm)	Average Current and Voltage
SC 3	53.38	1.60	32.39 – 135.12	21.74 – 222.42	164 A / 19.7 V
GLOB 3	74.61	1.46	43.83 - 122.35	19.58 - 224.31	248 A / 34.5 V
SP 3	54.35	1.56	33.52 - 103.20	14.67 – 168.87	310 A / 36.2 V
RMD 3	45.38	1.71	24.32 – 93.13	12.45 – 182.65	153 A / 18.1 V
FFPC 2	45.15	1.55	25.63 – 81.88	18.47 – 159.65	166 A / 33.1 V
FFPC 5	34.41	1.60	24.10 – 80.0	10.57 – 167.52	266 A / 34.3 V
FFPC 7	38.09	1.46	23.20 – 73.06	14.01 – 121.37	284 A / 34.8 V

- All tested conditions presented primary particles spanning from ~10 to ~200 nm
- Reduction in geometrical mean diameter for RMD and PULSED (current controlled), while Constant Voltage modes, the primary particle presented greater GMD.
- Smaller PP diameters for PULSED might be related to higher cooling rates due to the transition between high current (pulse peak ~450A) to lower (background curt. ~70 A)
- PP's showed distinct morphologies within same metal transfer mode, and no uniform pattern was observed.

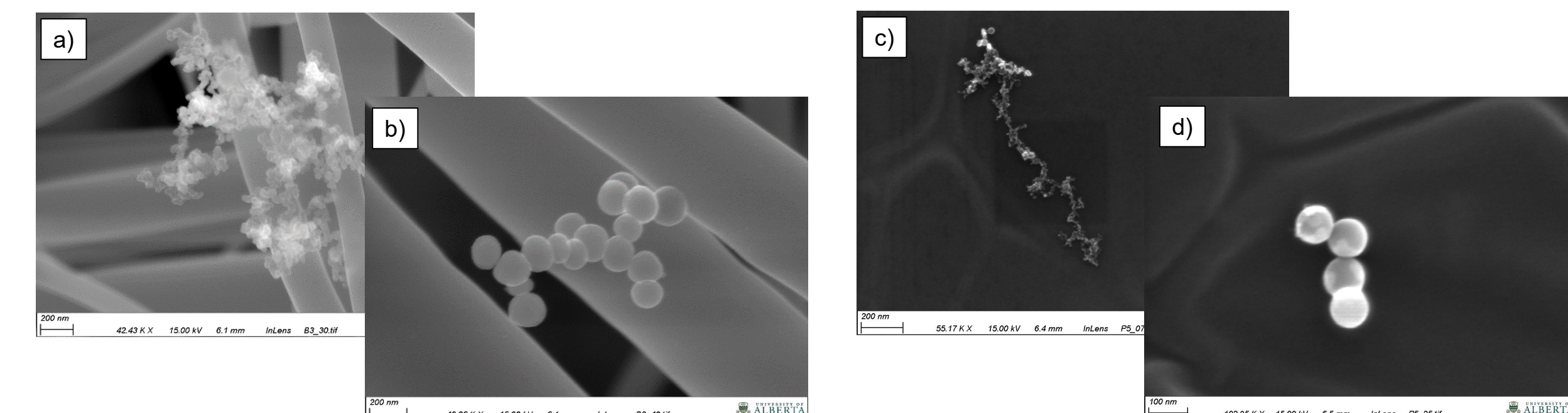


Fig 10. Examples of weld fume particles with different morphologies. a) and b) SC-2; c) and d) FFP-5

Conclusions

- For all metal transfer modes, aggregate particle sizes spanned from 20 to 400 nm with overall Count Median Diameter (CDM) of 122 nm.
- Regulated Metal Deposition and free-flight pulsed presented lower CMD compared to constant voltage modes (Short circuit, Globular and Spray).
- Within all tested conditions, primary particles (PP) diameters spanned from ~10 to ~200 nm. Free-flight pulsed presented smaller PPs, with overall average diameter of ~34 nm (exp. ID FFPC_P5)

Acknowledgements

