Master’s Thesis Engineering Technology

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Coating optimisation for fabrication of 3D printed electrodes used in hydrogen technologies

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Introduction

Background

- Rising **global energy demand** and the push for **carbon neutrality** drives the need for sustainable energy technologies.
- **Proton Exchange Membrane Fuel Cells** (PEMFCs) are clean and efficient devices for converting **green hydrogen** into electricity [1].
- Major barrier: their large-scale adoption is limited by **high cost** of **platinum (Pt)** based catalysts; optimisation needed for efficient use of Pt. —> Pt accounts for **20-25%** of the total PEMFC cost [2 p.10].

Aims

Develop the optimal deposition method depending on whether **performance**, **material efficiency** or **scalability** is prioritised.

Objectives

Identify the most **cost-efficient**, **uniform** and **scalable Pt coating** method to balance performance, material usage and manufacturing cost.

This study investigates four coating techniques for Pt/C deposition:

- Jetting
- Air spray coating (ASC)
- Hand spray coating (HSC)
- Ultrasonic spray coating (USC)

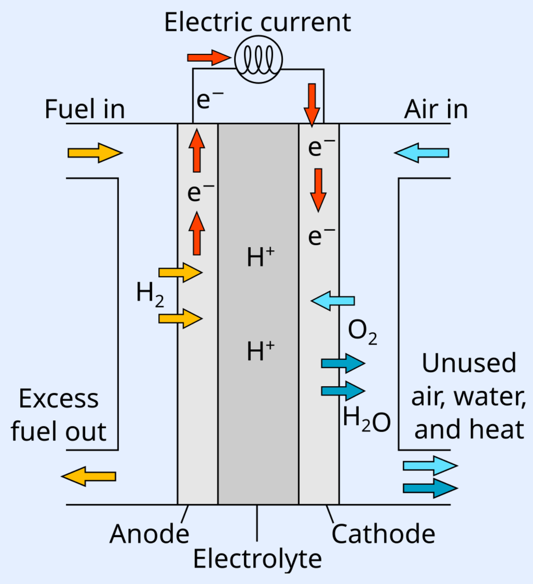
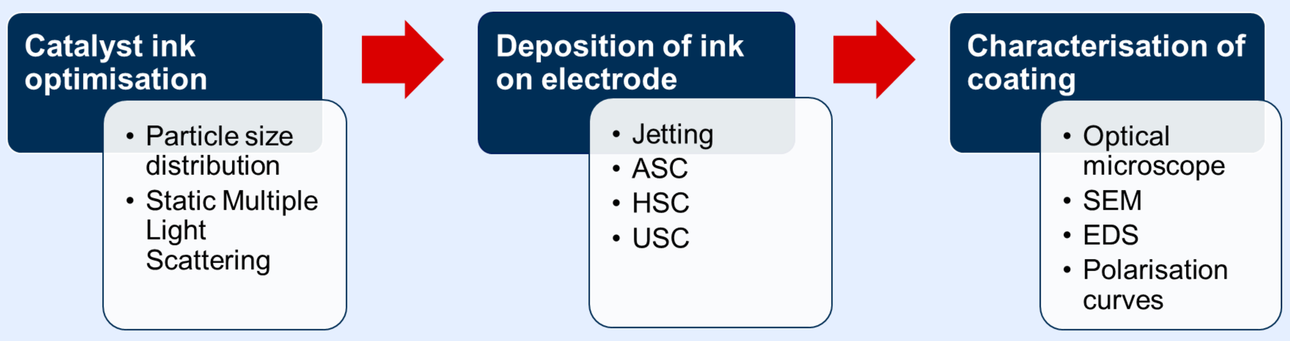


Figure 1. Schematic of working principle of PEMFC [3 p.982]

Methodology

The following process was used to evaluate each coating method:



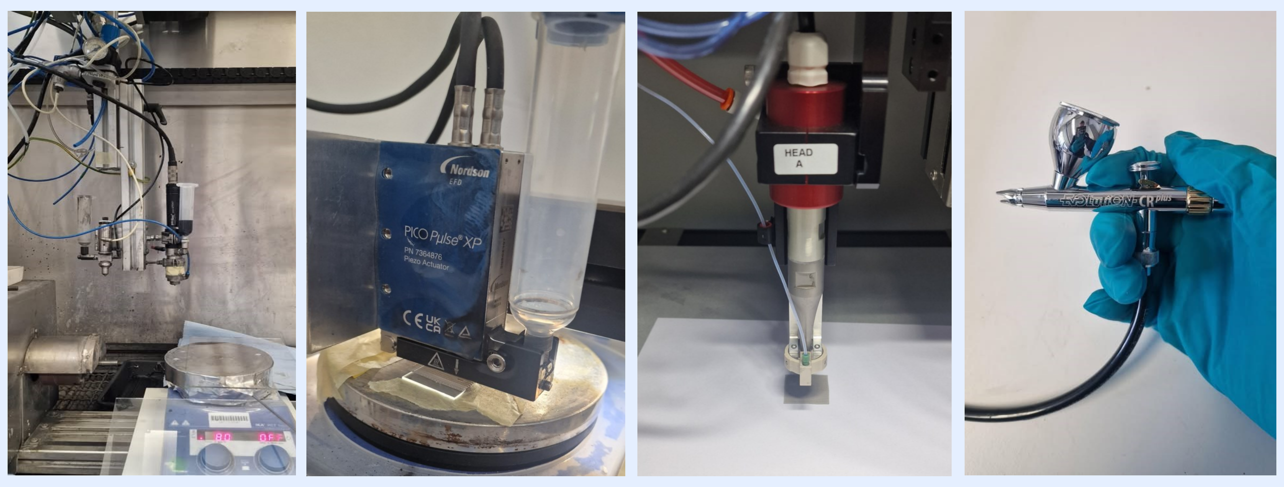


Figure 2. Experimental setups for each coating technique, from left to right: ASC, Jetting, USC and HSC

Each method was evaluated not only for performance, but also for practical feasibility by optimising important scalability parameters (coating duration, Pt/C loading), as shown in Table 1.

Table 1. Coating results for medium (ca. 0.77 mg_{Pt}/cm^2) loading on each sample

Method	Hours	Ink Vol (ml)	Pt used (mg)
ASC medium	4	120	90
Jetting medium	3	8	6
USC medium	3	50	37.5
HSC	>3	>150	112.5

Results

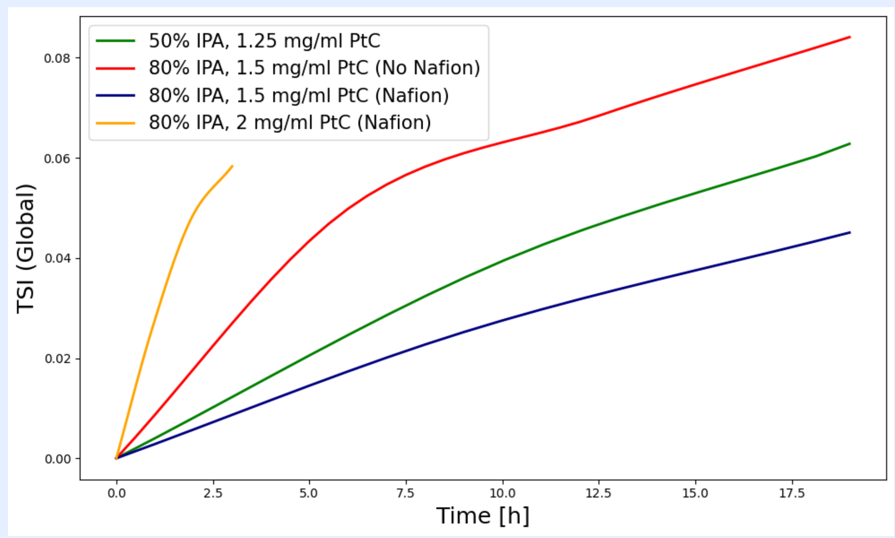


Figure 3. Suspension stability: TSI values of different ink formulations and impact of Pt/C concentration and Nafion® in various water/IPA ratios.

Ink optimisation using Turbiscan Stability Index (TSI)

- TSI quantifies ink destabilisation over time (Figure 3)
- Increasing Pt/C conc. > 1.5 mg/ml reduced stability.
- Absence of Nafion® resulted in more sedimentation —> higher TSI.
- Final formulation: 80% IPA + Nafion® + medium Pt/C = optimal balance of shelf life and evaporation speed.

Morphological analysis and Pt distribution

- Optical microscopy confirmed full mesh surface coverage, ruled out possible defects and showed roughness of 3D coated mesh.
- SEM and EDS analysis:
  - ⇒ ASC (Figure 4a): Thin layer with coarse particles in the coating surface.
  - ⇒ Jetting (Figure 4b): less uniform, shows multiple coated layers on top of each other. Pt penetrated deeper into pores of the mesh; lower surface coverage and uniformity (Figure 5a).
  - ⇒ USC (Figure 4c): smooth, continuous layer with little to no big particles. Most homogeneous Pt distribution in EDS (Figure 5b).
  - ⇒ HSC (Figure 4d): Uniform layer, with medium particle sizes.

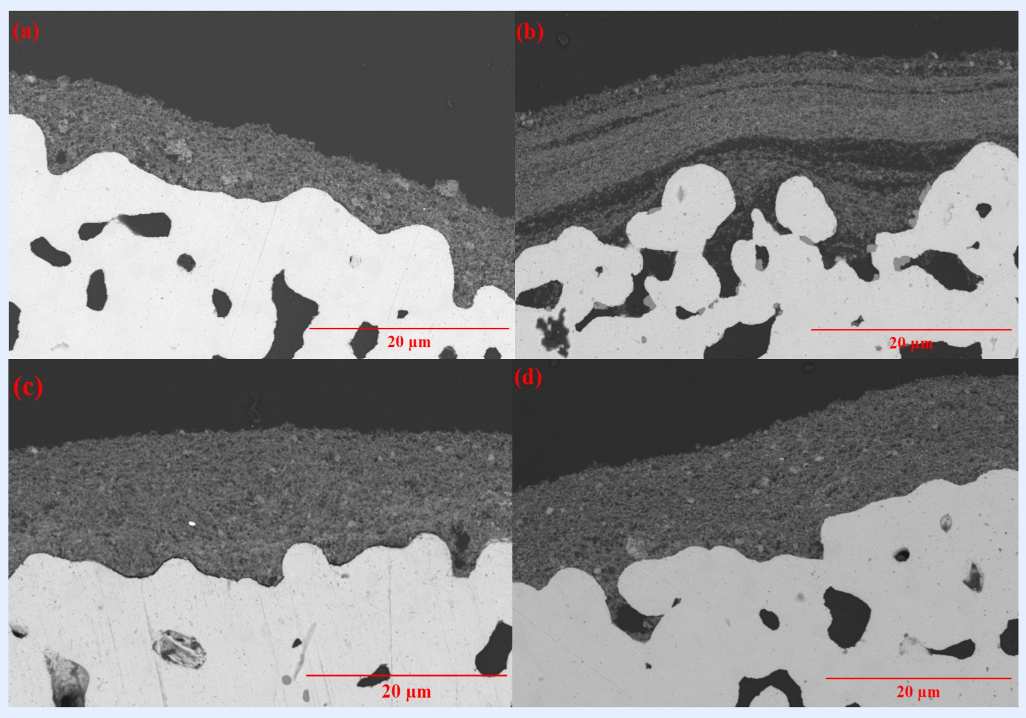


Figure 4. SEM images showing differences in surface morphology between ASC (a), Jetting (b), USC (c) and HSC (d) coatings for medium loading (ca. 0.77 mg_{Pt}/cm^2 Pt/C) at 2500x magnification

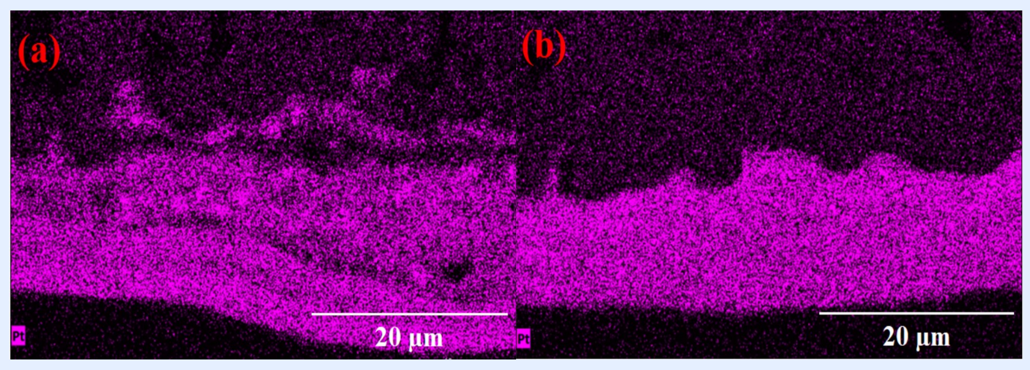


Figure 5. EDS images showing the difference in Pt distribution for jetting (a), USC (b) for medium loading at 2500x magnification

Fuel cell performance (polarisation curves)

- Doubling Pt loading does not double performance (Figure 6a).
- Jetting medium: Lowest performance but with the least Pt usage during coating (Figure 6b).
- USC medium: high performance with medium Pt usage during coating (Figure 6b).
- ASC medium: best performance but very high Pt usage during coating (Figure 6b).

Table 2. Maximum power and corresponding voltage and current density from each polarisation curve for representative coatings with average medium Pt loading of ca. 0.77 mg_{Pt}/cm^2 (USC was compared for medium and high loading, the latter illustrating the extent of process feasibility and reproducibility)

Technique + loading	Pt loading (mg_{Pt}/cm^2)	Max Power Density (mW/cm^2)	Voltage (V)	Current Density (mA/cm^2)
ASC medium	0.75	4.67	0.17	26.85
Jetting medium	0.77	2.67	0.27	10.03
USC medium	0.78	4.07	0.30	13.74
USC high	1.85	7.12	0.31	22.73

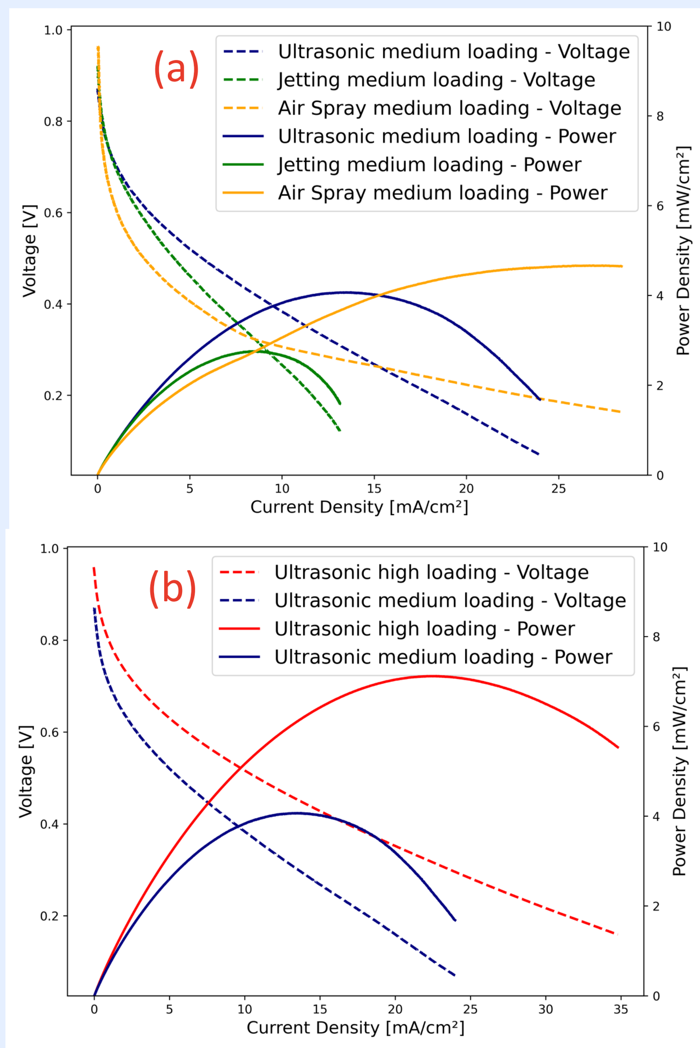


Figure 6. Voltage and power density in function of current density for medium loading comparison (a), high and medium loading (b)

Conclusion

The tested **deposition methods each show distinct trade-offs**. A maximum power density of **4.67 mW/cm²** was achieved with **ASC** but it used the **most Pt** during coating. The jetting-based coating resulted in the lowest performance (**2.67 mW/cm²**) but was the **most Pt-efficient** for coating electrodes with an optimal (medium) loading of 0.77 mg_{Pt}/cm^2. **USC** provided a **balance** between a maximum power density of **4.07 mW/cm²** and a **medium Pt usage** for the coating. The choice of method for this application depends on the intended application focus, which can be **efficiency**, **cost** or **sustainability**. In terms of **scalability**, ASC and USC are more suited for automated, high-throughput manufacturing than jetting and hand spraying.

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[1] B. Paul and J. Andrews, “PEM unitised reversible/regenerative hydrogen fuel cell systems: State of the art and technical challenges,” *Renewable and Sustainable Energy Reviews*, vol. 79, pp. 585–599, 2017, doi: https://doi.org/10.1016/j.rser.2017.05.112.
[2] F. A. De Bruijn, “PEM Fuel Cells Durability and Cost,” in *Hydrogen and Fuel Cells in the Nordic Countries 2009*, Oslo, Nov. 2009, pp. 1–46.
[3] *Y. Wang, K. S. Chen, J. Mishler, S. C. Cho, and X. C. Adroher, “A review of polymer electrolyte membrane fuel cells: Technology, applications, and needs on fundamental research,” Appl Energy, vol. 88, no. 4, pp. 981–1007, Apr. 2011, doi: 10.1016/j.apenergy.2010.09.030.*

De opleiding industrieel ingenieur is een gezamenlijke opleiding van UHasselt en KU Leuven