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Compression Moulded Flow Fields for Redox Flow Batteries

Edwin Harvey
Dr Oana Istrate, Prof. Peter Nockemann and Dr Stephen Glover

QUILL Meeting, 26th March 2024

CONFIDENTIAL

Redox Flow Battery (RFB)

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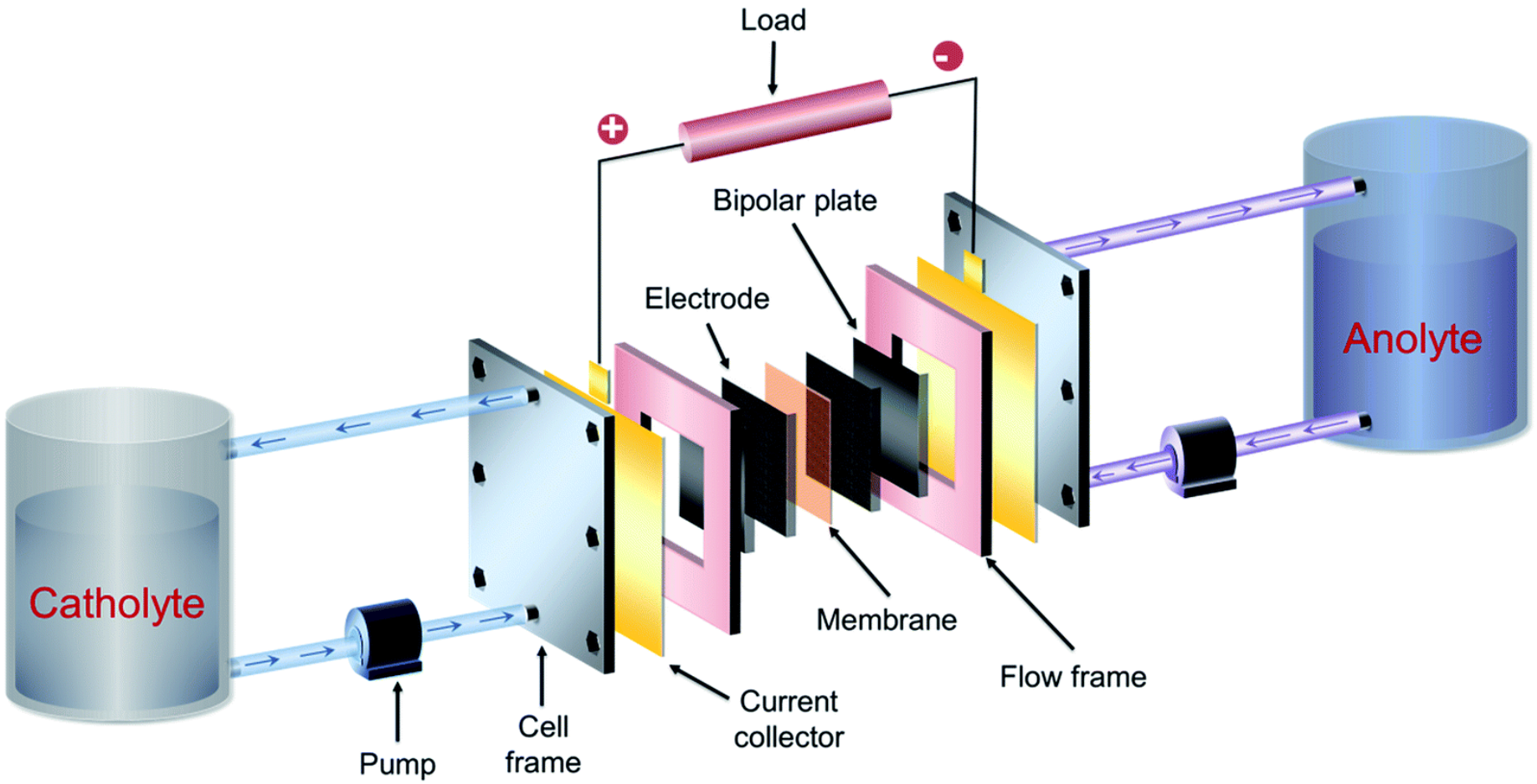
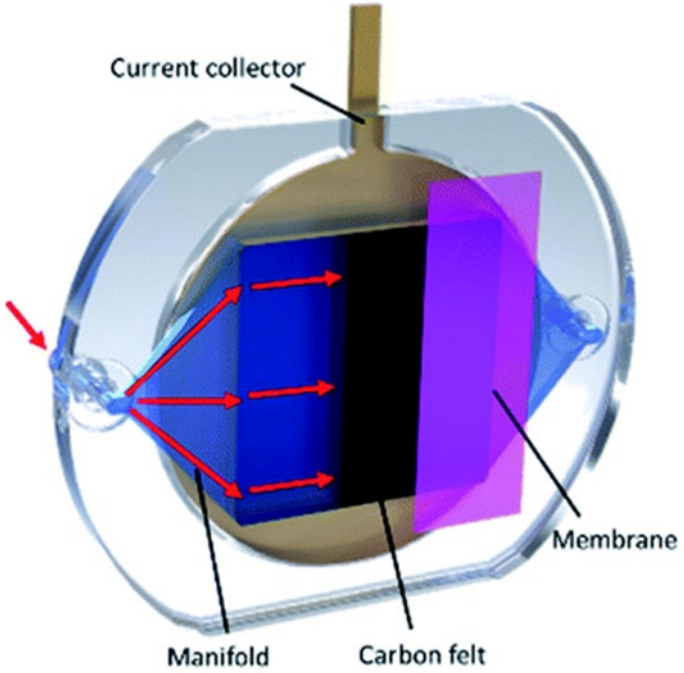
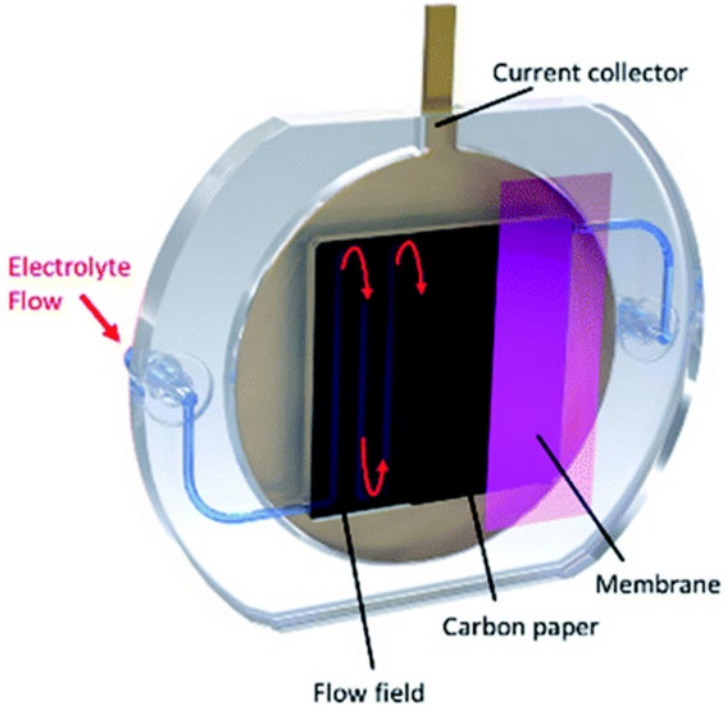


[1] Kim, K. J. *et al.* A technology review of electrodes and reaction mechanisms in vanadium redox flow batteries. *J. Mater. Chem. A* (2015).

Flow-through vs Flow-over



- Thicker felt electrodes
- Electrolyte flows-through electrodes
- Higher pressure drop
- Simpler to manufacture



Figures from [2]

- Thinner paper electrodes
- Electrolyte flows-over **flow field** channels
- Minimal pressure drop
- More complex to manufacture [3]

[2] O'Connor *et al*. An open-source platform for 3D-printed redox flow battery test cells. *Sustainable Energy & Fuels* (2022).
[3] Sun *et al*. Redox flow batteries and their stack-scale flow fields. *Carbon Neutrality* (2023).

Flow Field Manufacturing

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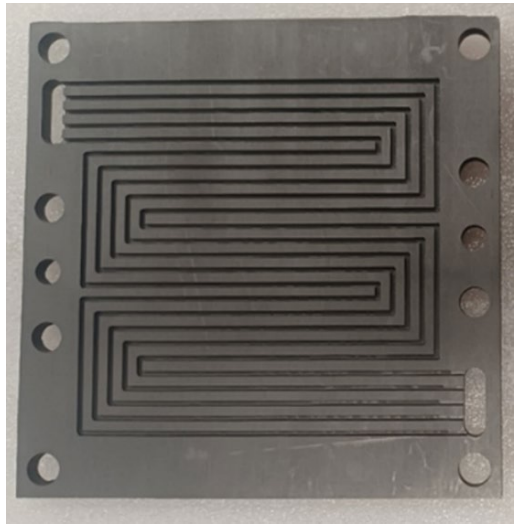
Existing method: Flow fields machined into graphite plates

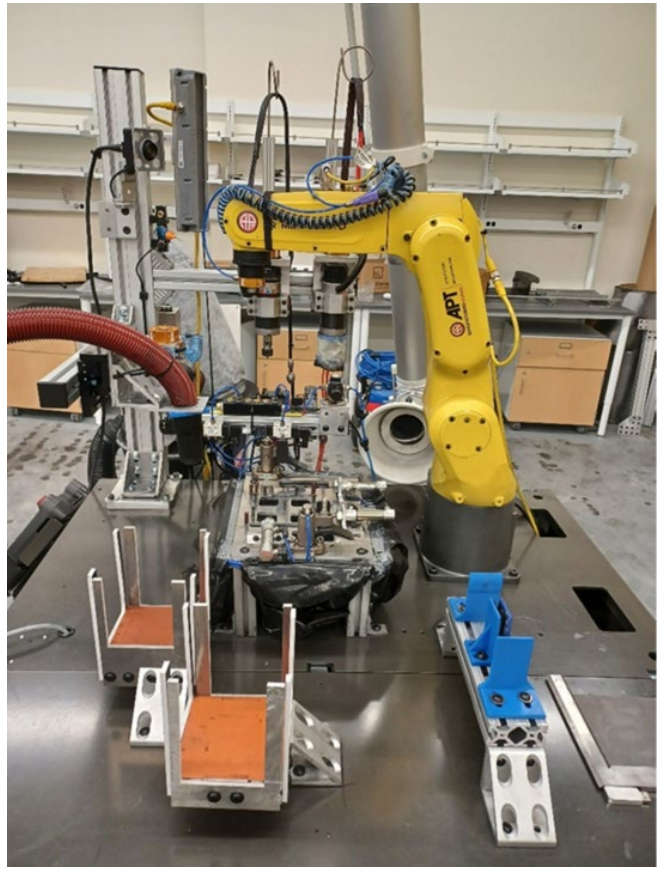
↗ **Time consuming**

↑ **High wear to tools**

↖ **Dangerous graphite dust generated**



Machined flow field using robotic manufacturing [4]



[4] Gurau & Kent. Robotic Manufacturing System for Unattended Machining and Inspection of Graphite Bipolar Flow Field Plates for Proton Exchange Membrane Fuel Cells. *Manufacturing Letters* (2022).

Flow Field Manufacturing

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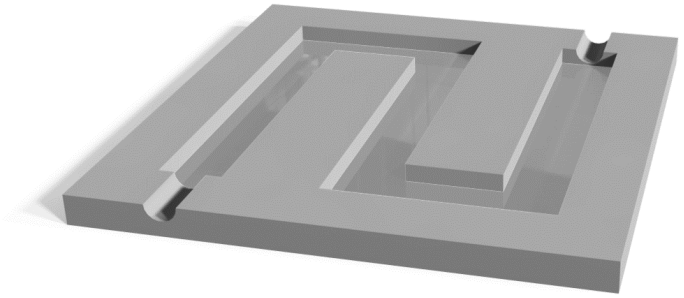
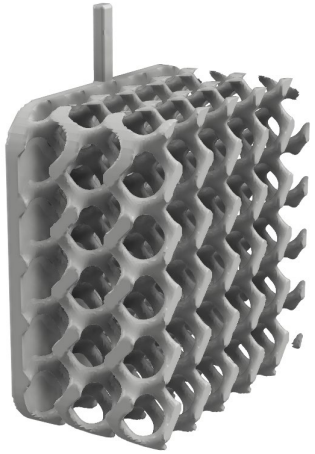
Proposed method: Manufacturing flow field parts using compression moulding of polymer composites

Synthesise composite material → **Form flow field shapes** → **Redox flow battery cell testing**



Flow field concept manufactured through compression moulding



Flow-through electrode concept manufactured through 3D printing

← **improve electrochemical properties**

← **improve electrolyte flow**

Composite Preparation

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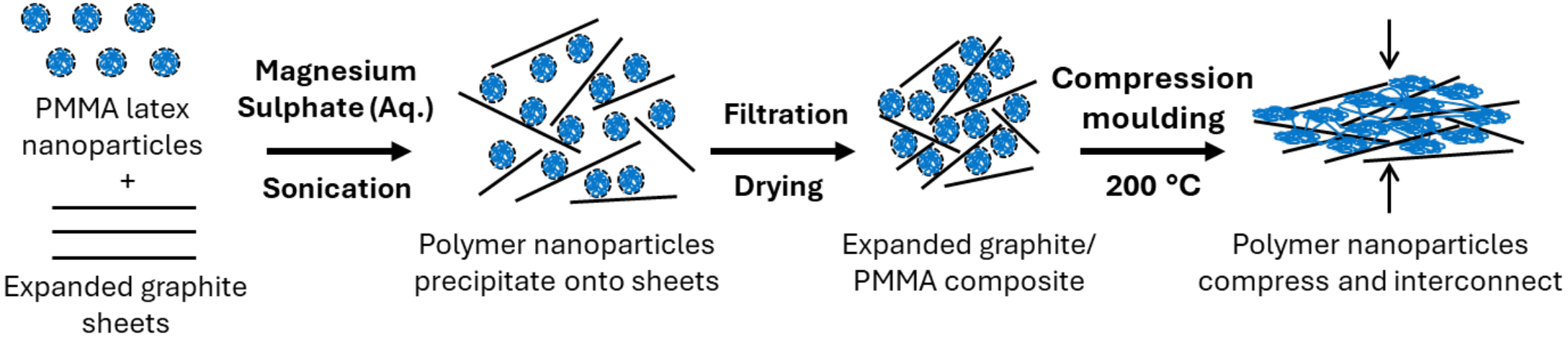
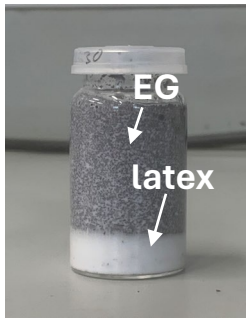
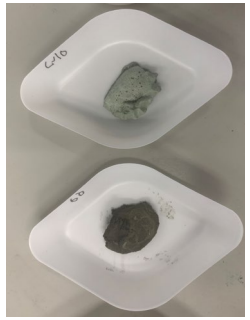
- Graphite and polymer combined using a latex blending procedure [5]







[5] Bourgeat-Lami, E., Faucheu, J. & Noël, A. Latex routes to graphene-based nanocomposites. *Polym Chem* (2015).

Material Characterisation

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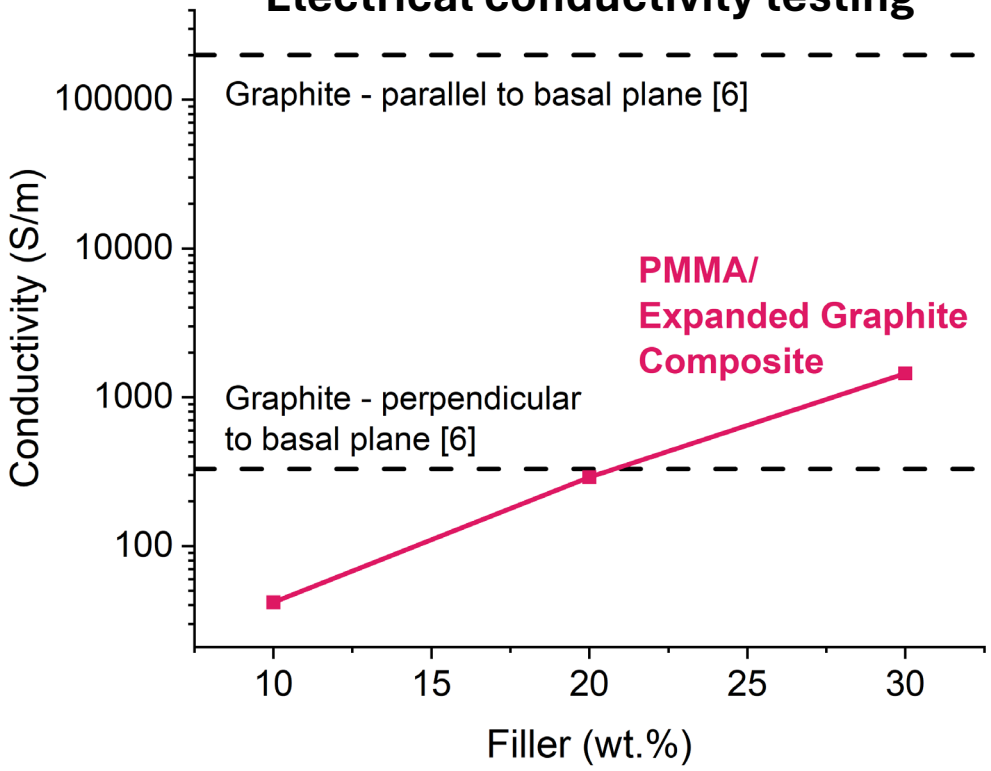
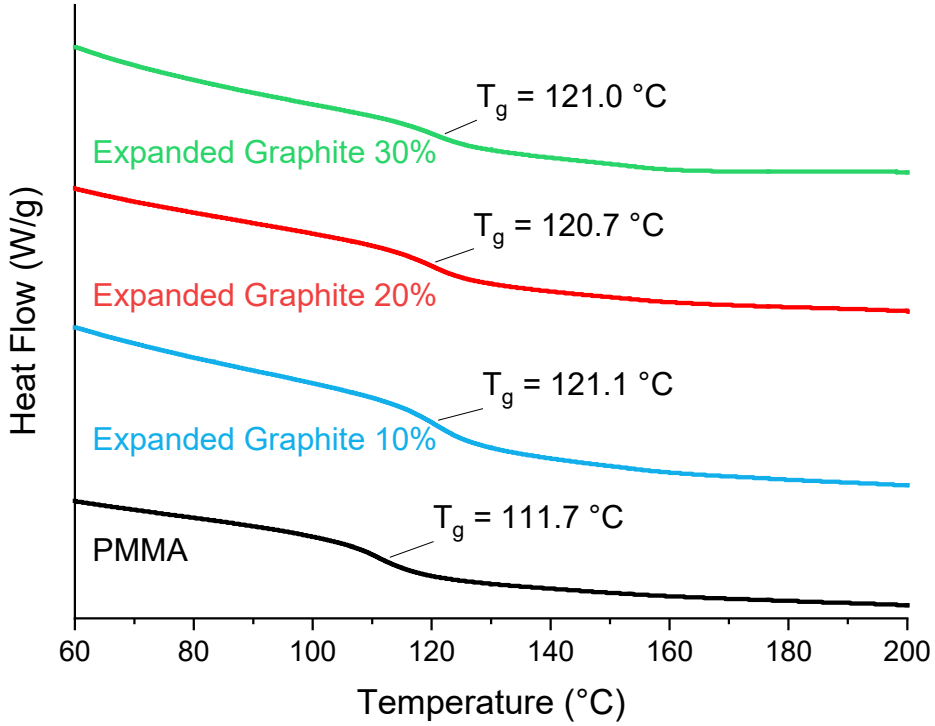
- PMMA/expanded graphite composite characterised adjusting expanded graphite wt.%
- 30 wt.% graphite composite achieved conductivity of 1445 S/m comparable to pure graphite
- T_g increases after adding expanded graphite to PMMA

Electrical conductivity testing



Differential scanning calorimetry (DSC)



[6] Pierson, H. O. Handbook of carbon, graphite, diamond, and fullerenes: properties, processing, and applications, p. 61 (1993).

Mould Manufacturing

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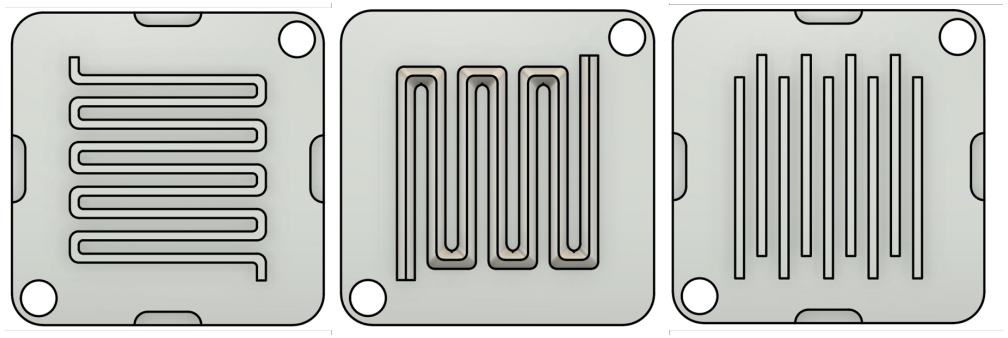
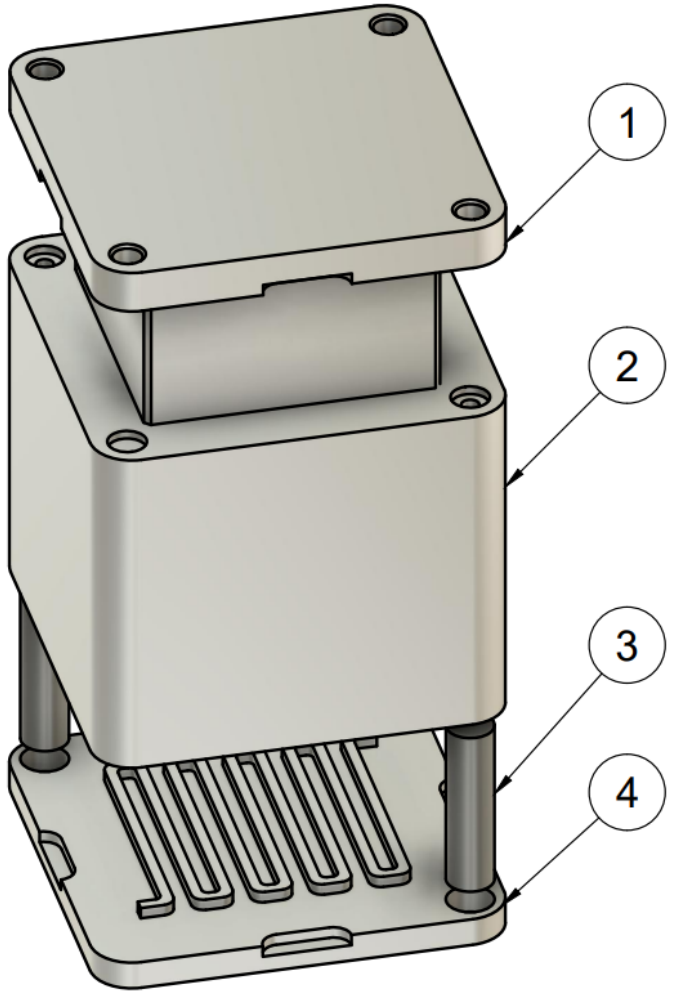
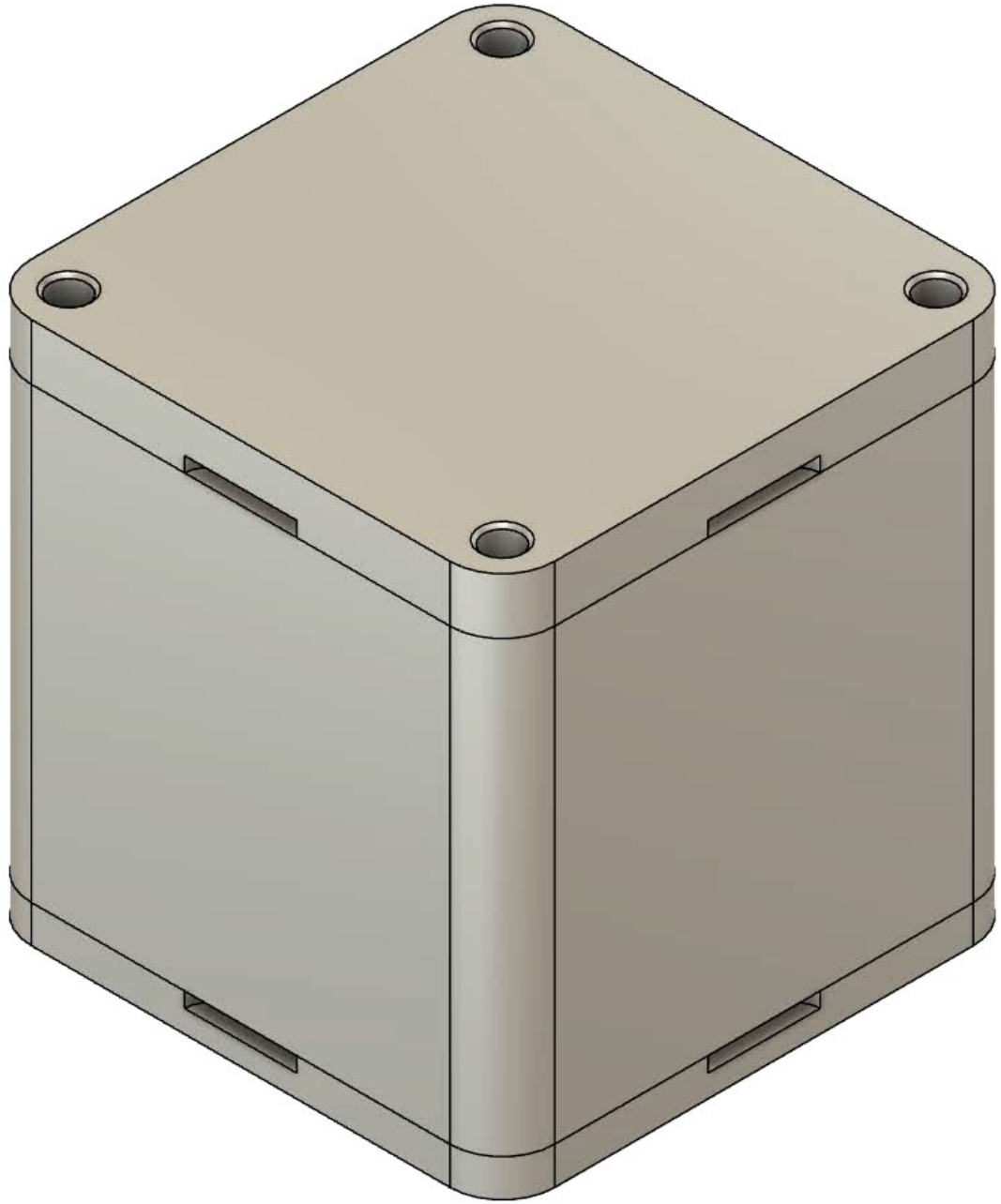
- Bespoke moulds were designed and manufactured by computer numerical control (CNC) using 6061 Aluminium alloy



Flow field mould can be swapped for different architectures





Flow Field Visual Inspection

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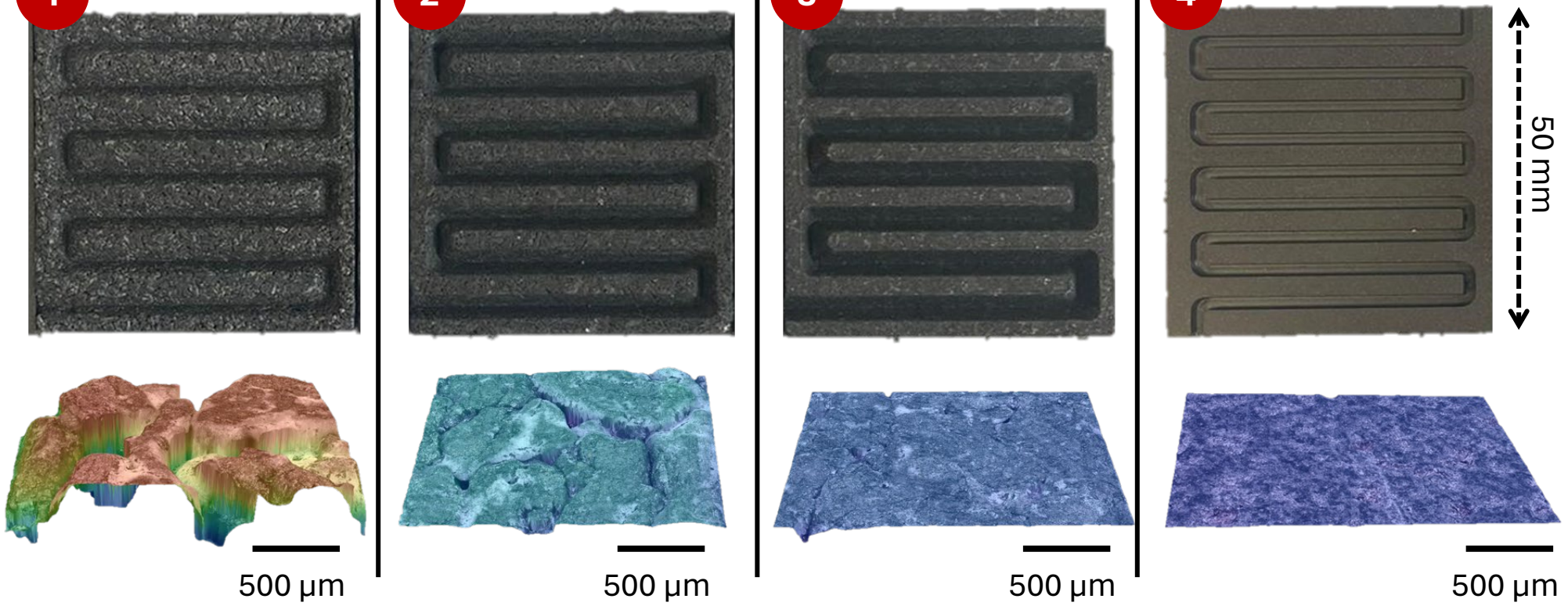
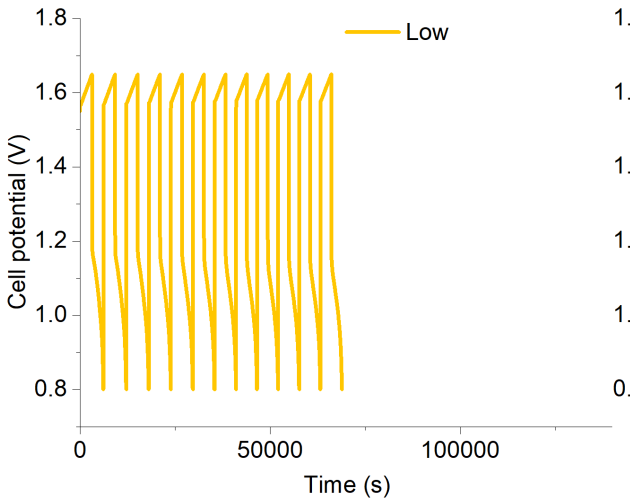
	Low density compression mould	Med density compression mould	High density compression mould	Commercial machined graphite
Density (cm^3/g):	0.25	0.5	0.7	1.96
Photographs:	1	2	3	4
Microscope 3D images (150x):	500 µm	500 µm	500 µm	500 µm

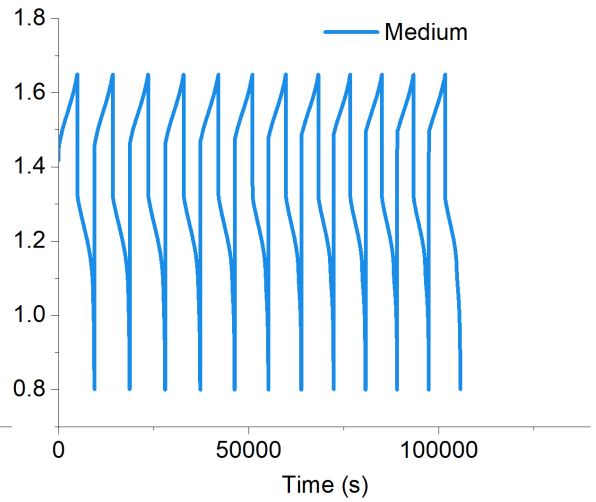


Cell Capacity Testing

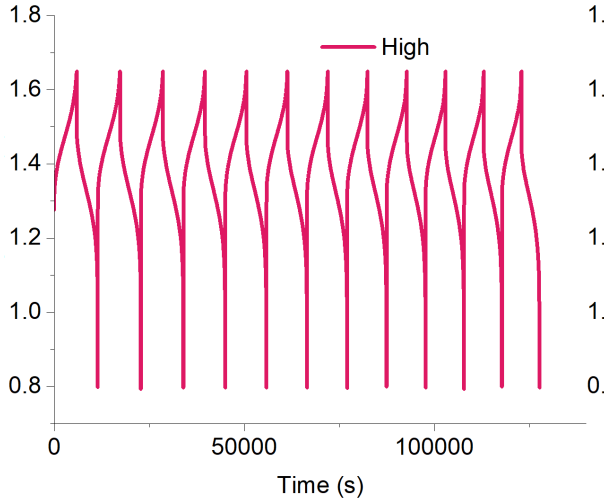
- Galvanostatic charge-discharge testing over 12 cycles performed
- Setup: Flow fields with carbon felt electrode in 3D-printed flow frame cell [7] using 1.6M vanadium electrolyte
- High density flow field has lower onset voltage than machined graphite



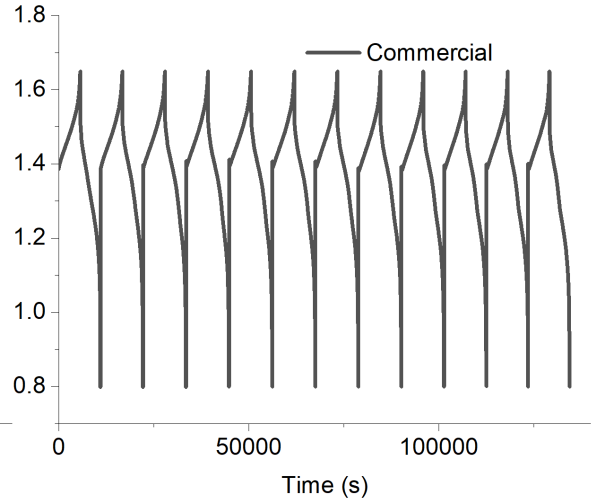
Low density compression mould



Med density compression mould



High density compression mould



Commercial machined graphite

[7] O'Connor *et al*. An open-source platform for 3D-printed redox flow battery test cells. *Sustainable Energy & Fuels* (2022).

Cell Capacity Testing

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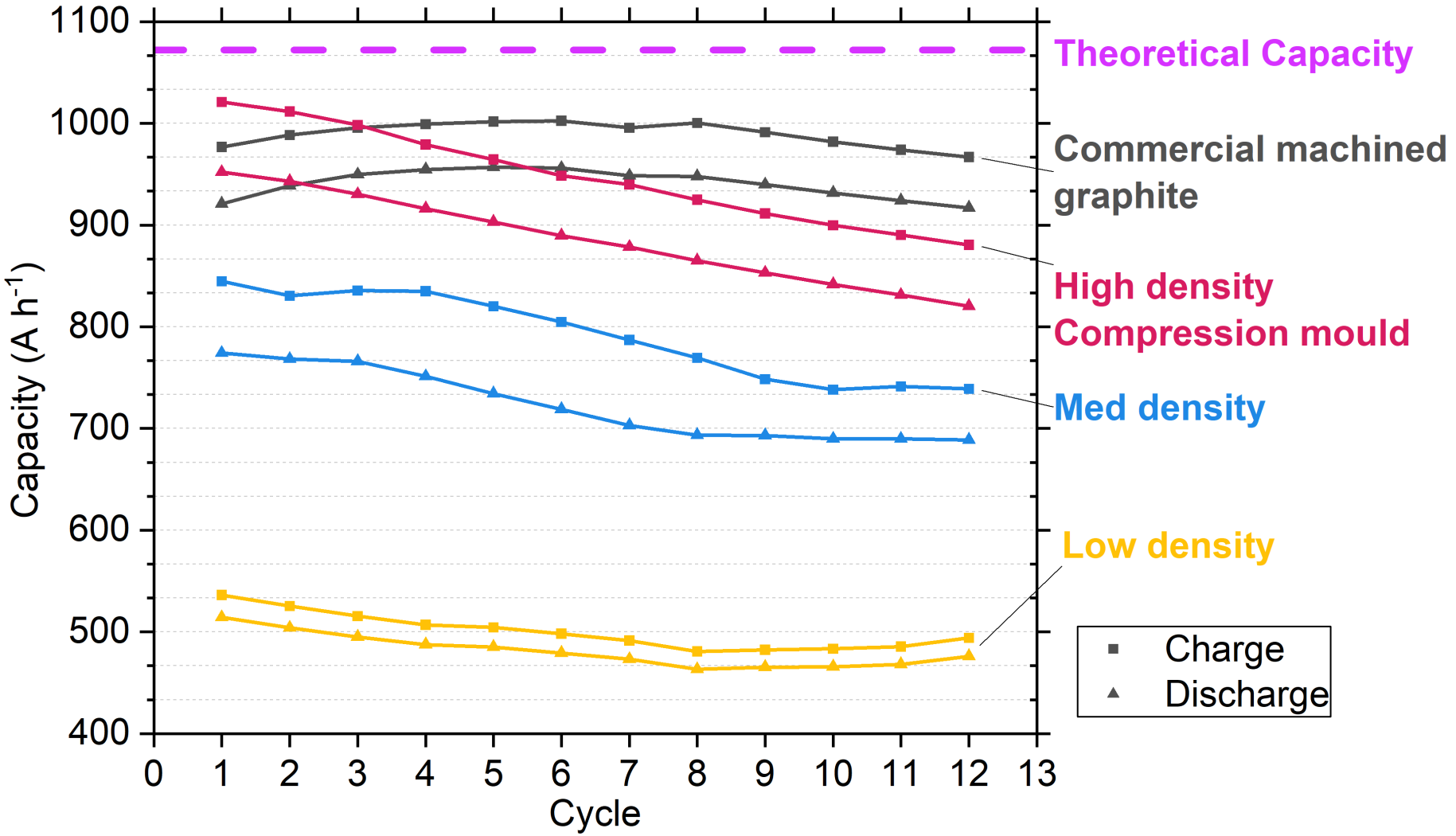
Charge and discharge capacity measured over 12 cycles

- High density compression mould has high initial capacity
- Experiences capacity fade over time
- Med and low density samples have low capacity probably due to poor conductivity



Cell Efficiencies

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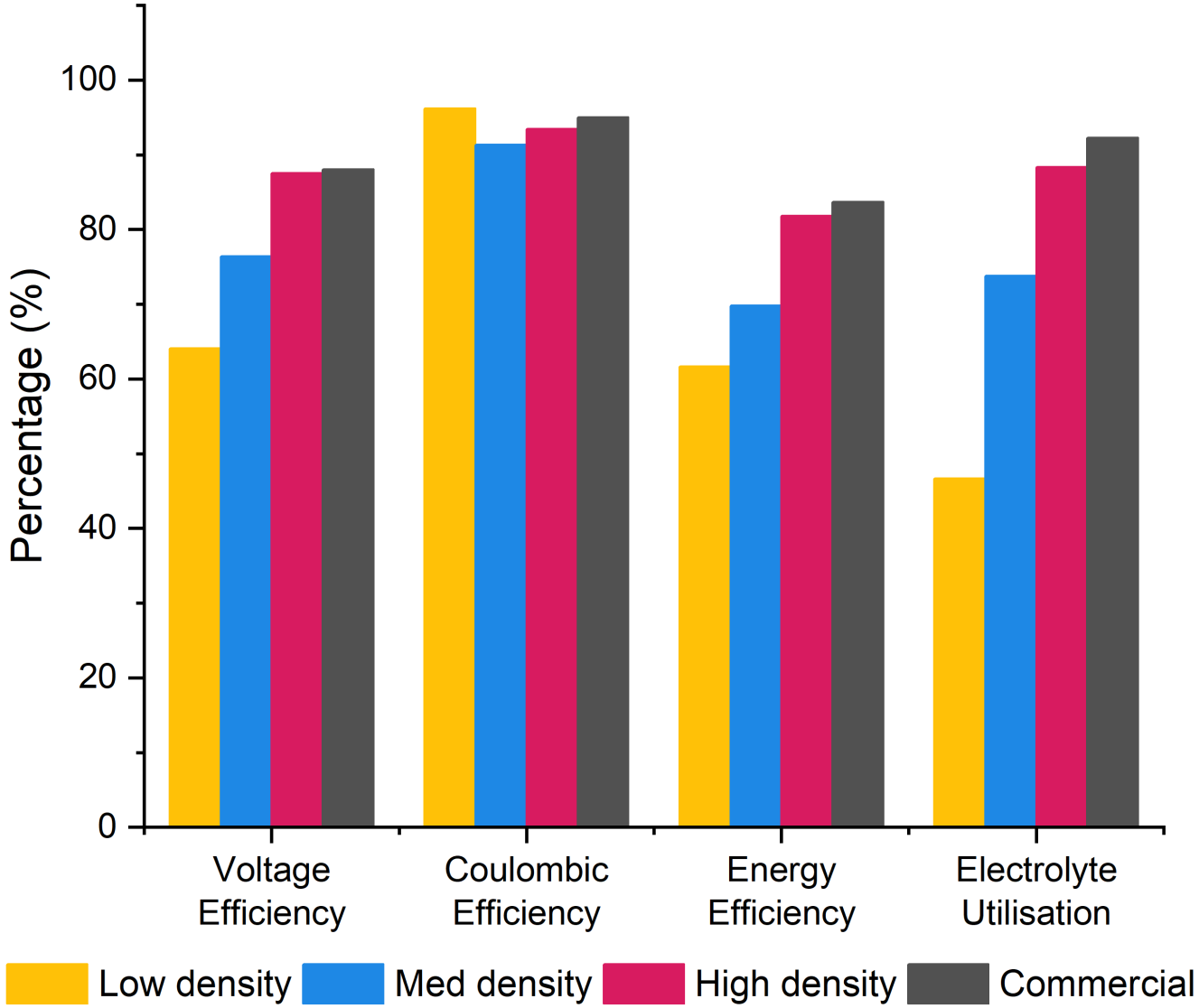
Average efficiencies and electrolyte utilisation over 12 cycles

- Energy efficiency increases with higher densities probably due to increased electrical conductivity
- Energy efficiency of 81.8% achieved for high density compression mould just 1.9% less than commercial graphite



Summary

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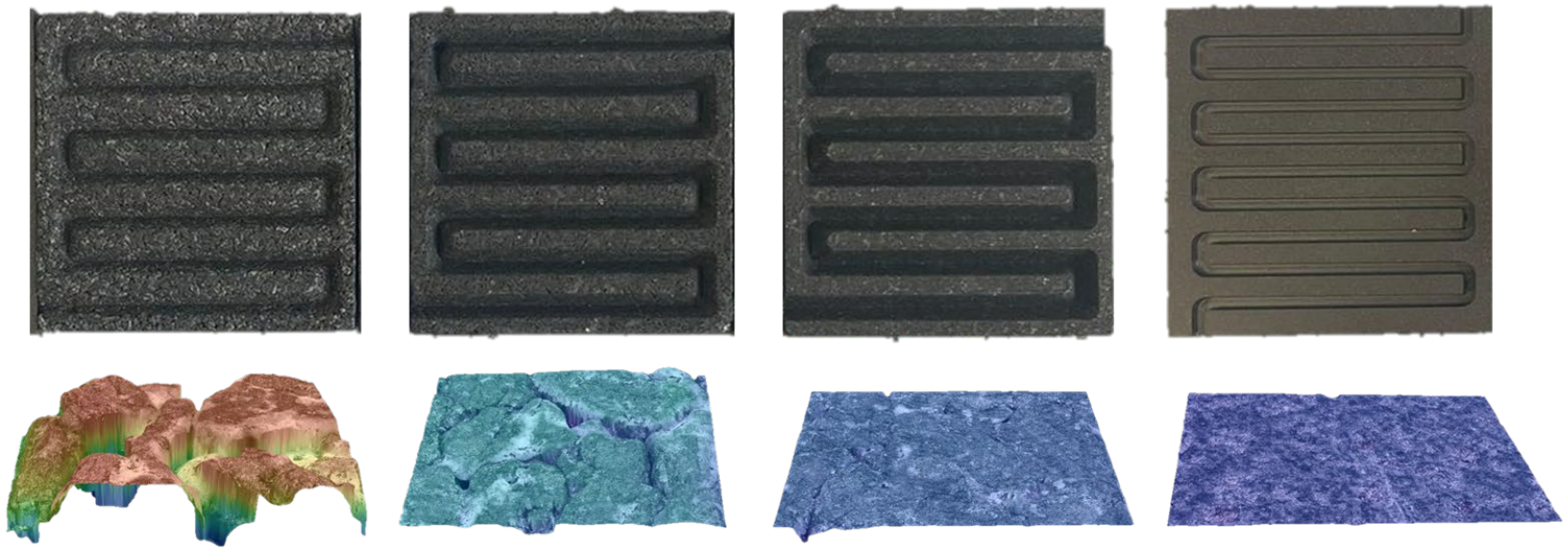
- Flow-over RFB cell testing shows comparable cell efficiencies to commercial flow field
- Compression moulded flow fields cheaper to manufacture and more versatile compared to machining graphite
- Promotes the use of flow fields in RFBs due to low costs and comparable performance



Future Work

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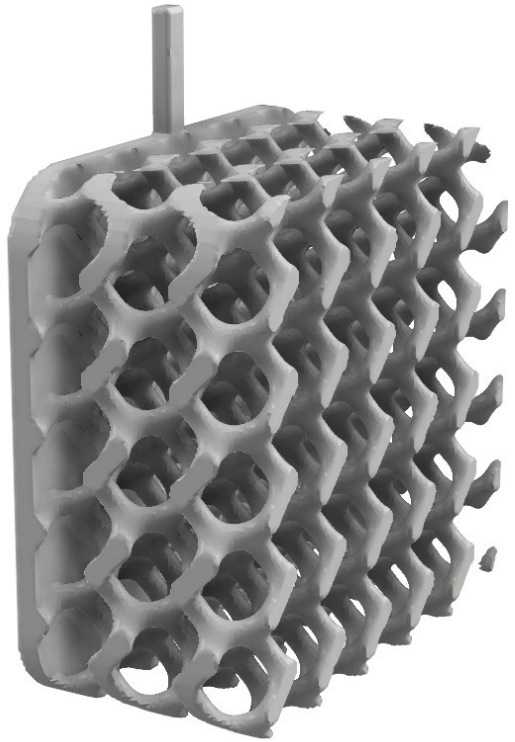
- Higher density flow field parts/ increased graphite content – to increase conductivity
- More detailed electrochemical characterisation – to understand capacity fade
- Modelling of electrolyte velocities through electrode and flow field architectures

Flow-through electrode concept manufactured through 3D printing



Acknowledgements

- Supervisors for ongoing support: Oana, Peter and Stephen
- Hugh and Josh for support in battery lab
- Ethan McCulla for help designing flow field mould
- Yoan for help in labs
- Peter Klusener for ongoing support
- PhD funded by Department for the Economy
- Queen’s University Ionic Liquid Laboratories (QUILL)
- Polymer Processing Research Centre (PPRC)

Cost Analysis – Moulding

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- Cost of producing 1 kg of PMMA/expanded graphite composite estimated at **£33 per kg** mostly associated with labour costs
- 10 g compression moulded flow cost **33 p per unit**

Material	**Cost £**	**Quantity per kg of composite**	**Cost £**
Methyl methacrylate	2 per kg *	0.8	1.6
Expandable graphite	5 per kg *	0.2	1
Coagulating salt	1 per kg *	0.1	0.1
Furnace/ Mixing power	0.3 per kWh	1	0.3
Labour	10 per hr	3	30
PMMA/expanded graphite composite			33

*Estimated costs from alibaba.com

Cost Analysis – Machining

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- Cost for machined flow field estimated at **£10.08 per unit**
- More expensive compared to compression moulding method (33 p per unit)

Material	**Cost £**	**Quantity per flow field**	**Cost £**
Graphite Block	5 per kg *	0.01	0.05
Machining power	0.3 per kWh	0.1	0.03
Labour	10 per hr	1	10
		Machined graphite flow field	£10.08

*Estimated costs from alibaba.com