Scottish Research Partnership in Engineering (SRPe) | NMIS National Manufacturing Institute Scotland | University of Strathclyde | Doncasters Bramah

# Electroforming of Large Scale Nickel Structures for Leading Edge Energy, Aerospace and Marine Applications


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***Electroforming*** is an electrochemical additive manufacturing process used to fabricate mechanically robust stress-free complex structures. Our team aspires to bring the process to the forefront of precision manufacturing and significantly contribute towards the realisation of electrochemical additive manufacturing processes in ***Industry 4.0*** era.

## [ Industry Challenge ]

Electrochemical forming currently remains an artisanal process, focused on the fabrication of specialised and complex parts. The industry challenge is to take this to the next tier of volume manufacturing. This will require a deeper understanding of the inter-relationship between fundamental engineering parameters with process limitations and derived material properties. This will allow predictability in tooling, choosing appropriate process factors, piloting for manufacturing, and relevant measurement protocols. This work will be the first attempt to use experimentally-informed simulation of the electroforming process, leading to volume production in Industry 4.0.

## [ Research Challenge ]

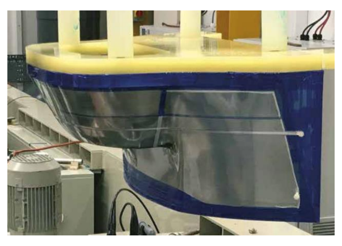
Electrochemical forming is currently used in manufacturing of niche and specialised products. However there is little scientific or technical understanding of the electrochemical or engineering parameters. The development of new chemistry and associated technology holds the key to its scale-up for volume manufacturing. To achieve this, the physico-chemical and electrochemical properties of the system need to be mapped and their effect on the structural and mechanical properties of the products explained. These data provide the knowledge base to simulate the process and verify by experiments. These validated models will then be used to propose optimised processes, based on which volume production in Industry 4.0 era can be achieved.

## [ Desired outcomes ]

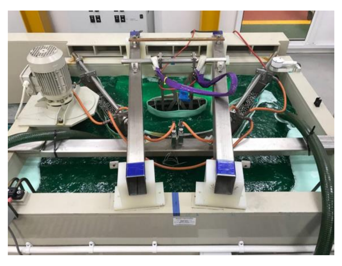
- ❑ This unique approach would help in upskilling the manufacturing process, people and supply chains in line with the Scottish & UK Governments' manufacturing strategy.
- ❑ Unique knowledge for an additive and sustainable electrochemical manufacturing method will be established. This will consist of:
  - ✓ Development of bespoke chemistry, well-designed reactors, tools and optimised processes.
  - ✓ Precise simulation modelling for the design of optimised manufacturing.
  - ✓ Fabrication of novel electroformed products for new markets.

## [ The Electroforming Process ]

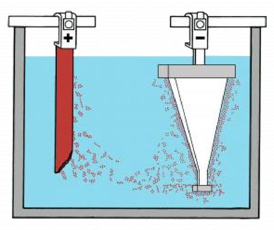
Anode baskets are loaded with nickel pellets.



The stainless steel mandrel (cathode) is thoroughly polished and cleaned.



Anode baskets and mandrel are introduced to the nickel sulphamate bath.



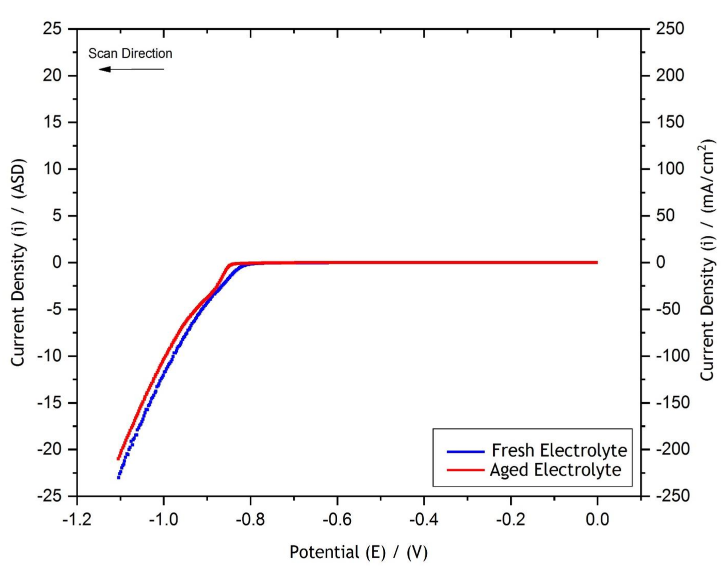
Current is applied, the agitation and temperature conditions are set.
Nickel ions are produced at the anode and are transferred through the electrolyte to the mandrel, where they deposit as metal.

When desired product thickness is achieved, the mandrel is removed from the bath and the part is detached.

The material properties are measured. The part is ready to be used as a structural unit.

## Experimentation at lab-scale provide important information on the system's electrochemical behaviour: (1) reaction rates of nickel (and hydrogen) vs. electrode potential and (2) current efficiency of deposition.

### What are the reaction rates of nickel and hydrogen at different applied currents?



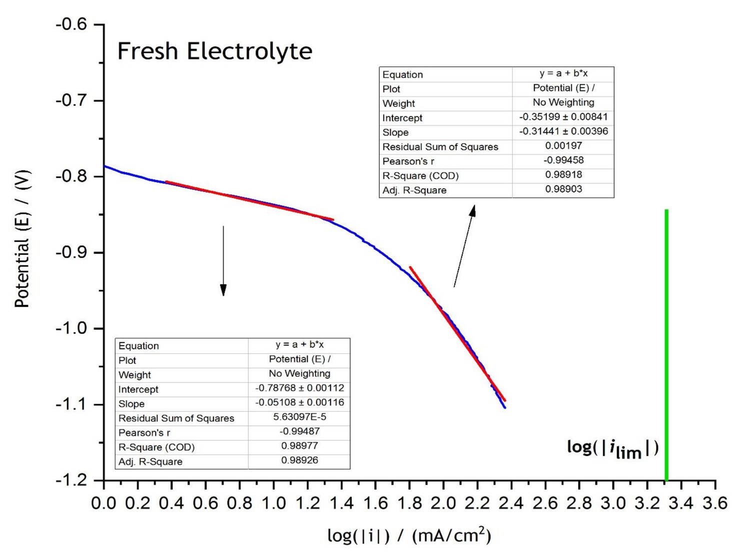

**Linear Sweep Voltammetry** experiments at 50 $^0C$, 1500 rpm and a scan rate at 0.005 $V/s$, propose that:

✓ Efficient deposition was determined between 10 – 12 ASD for the pure sulfamate solution.

✓ Nickel deposition is "slower" for the aged electrolyte. Imply divergent behaviour for laboratory and industry environments.

✓ This provides the current potential behaviour for the co-production of Ni and Hydrogen. Current efficiency measurements have to be carried out to determine the current for Nickel.

### Which parameters should be used as input in the model?




Tafel plots provide most of the input parameters. The two linear areas indicate a change in mechanism as the second linearity appears below the limiting current value at $\boldsymbol{i_{lim}}$ **= 2081.38 mA / cm²** .

$$E_{eq} = E^0 + \frac{0.059}{2}\log[Ni^{2+}]$$

$E^0$ (vs SCE) / $V$: -0.501 $V$ → $E_{rev} = -0.492\,V$ *(ignoring activity effects)*

$$i_{lim} = \frac{zFD_{eff}}{\delta} \times c_{Ni}$$

**z**: ions exchanged $= 2$
**F**: Faraday constant $= 96485\ C \cdot mol^{-1}$
$\mathbf{D_{eff}}$: Diffusion coefficient $= 5.55 \cdot 10^{-6}\ cm^2 s^{-1}$
$\mathbf{c_{Ni}}$: Nickel concentration in solution $= 2.07\ M$
$\boldsymbol{\delta}$, $boundary\ layer = 1.07 \cdot 10^{-3}\ cm$

$$a = \frac{-2.303RT}{a_a F} \times \log i_0$$

→ $a_1^A = 1.257 \;/\; a_2^A = 0.204$

$a_1^B = 2.564 \;/\; a_2^B = 0.234$

### How fast a nickel electroforming process could be?

The fresh electrolyte provided deposits of higher quality while, the aged electrolyte favoured dendritic growth. Dendritic nickel (seen at the edges of the plated disc) are formed due to mass transfer limitations or very high current density. The figures show possible intense mass transfer phenomena at the edges with the aged electrolyte. Most of the nickel deposited with the aged electrolyte contributes to the formation of dendrites rather than useful deposit area, which is a loss to the process. Deposition experiments conducted at 50 $^0C$ and 1500 rpm, for 30 *min*.

| $i_{app}$ (ASD) | Thickness (μm) | Deposition Rate (mm / h) |
|---|---|---|
| 42.233 | 281.56 | 0.56 |
| 19.709 | 154.18 | 0.308 |
| 3.981 | 44.46 | 0.089 |
| 1.07 | 7.3 | 0.015 |

## Experimental Lab Setup

- ❑ Metrohm Autolab Potentiostat/Galvanostat
- ❑ Water bath
- ❑ Double-wall Lab Cell
- ❑ Rotating Disk Electrode (WE)
- ❑ Nickel Anode (CE)
- ❑ SCE RE
- ❑ Stainless Steel Disk Mandrels

A power supply was used for deposition experiments to represent better the industrial process (current-controlled process).

## Future Plans

- ✓ Simulation modelling of the experimental process using COMSOL@.
- ✓ Manufacturing of a 15*L* electroforming tank to be accommodated at University of Strathclyde.
- ✓ Deposition experiments in the prototype electroforming tank.
- ✓ Deposits' structural and mechanical characterisation.
- ✓ Simulation modelling and verification of the lab scale process using COMSOL@.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