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 in *"the production or reproduction of articles by electrodeposition upon a mandrel or mould that is subsequently separated from the deposit" providing* 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 scaled-up, volume manufacturing. This requires the efficient bridging of the gaps among electrochemistry, chemical engineering, and manufacturing, to allow for predictability in tooling, optimisation of process factors, piloting for manufacturing, and relevant measurement protocols.

This work succeeded in initiating the bridging of those gaps through systematic experimental studies in different production scales, the development of well-informed nickel electroforming models, and the identification of the key parameters to be considered during process optimisation, leading to up-to-date, sustainable, production that meets the *Industry 4.0* requirements.

[Research Challenge]

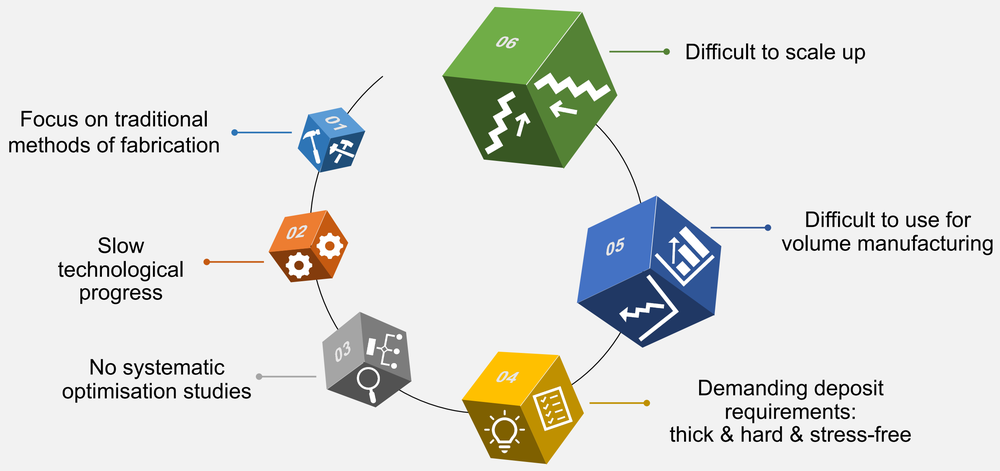
Electrochemical forming's capability to manufacture a variety of niche components has been exploited in micro-manufacturing, as well as large-scale manufacturing. As the *Industry 4.0* era unfolds, there is a need to develop models for electroforming which are based on electrochemically sound data. To achieve this, the physico-chemical and electrochemical properties of the system were mapped and their effect on the structural and mechanical properties of the products explained. These data provided the knowledge base to simulate the process and verify by experiments. The validated models were then used to propose optimised processes, based on which scaling-up for volume manufacturing can be achieved.

[Outcomes]

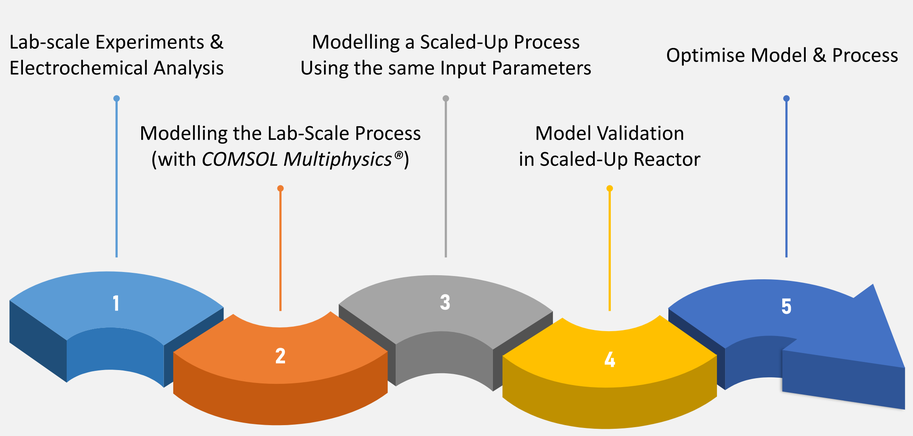
Qualitative results and proposed methodologies could confidently be applied in industry towards the systematic study and successful optimisation of the electroforming process, regardless the scale of application and volume of production. The proposed approach could help towards a "green transition" in high-precision manufacturing, allowing for sustainability in materials, process and distribution, in line with the Scottish & UK Governments' strategy.

Unique knowledge of a sustainable electrochemical manufacturing method was established, rendering the development of efficiently designed reactors, appropriate tooling and optimised processes possible. This knowledge was gained through systematic experimental studies in both the laboratory and industrial scales, well-informed simulation modelling and successful fabrication of electroformed products for aerospace applications.

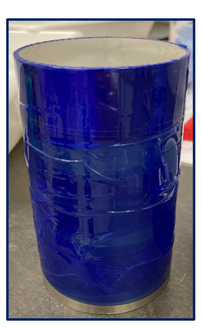
[Around since early '60s but not mature…]



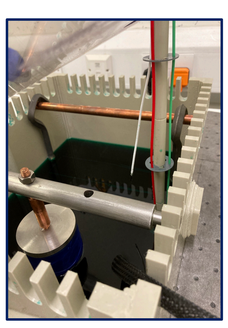
[Electroforming 4.0: There is a Way!]



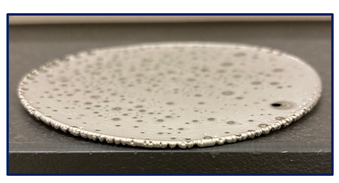
[In Practice…]



Stainless-Steel Mandrel

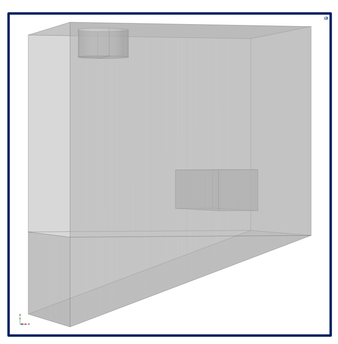


Electrodeposition in Nickel Sulphamate (18 L Tank)

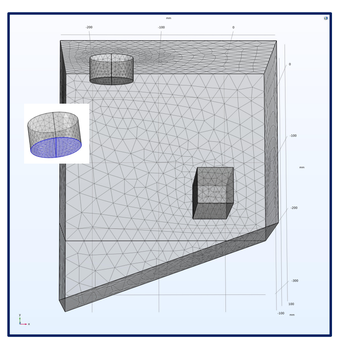


Stand-Alone Product
$A_{cyl} = 0.31\ dm^2$

[In the Model…]



Create the Geometry



Build the Mesh

Boundary and Initial Conditions

✓ Cell potential governed by Laplace's equation

✓ Concentration uniform throughout the electrolyte volume

$\nabla^2 \Phi = 0$

Insulation

No current can pass!

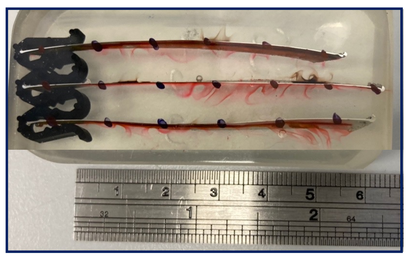
$-n \cdot i_l = 0, -n \cdot i_s = 0$

Electrode-Electrolyte Interface

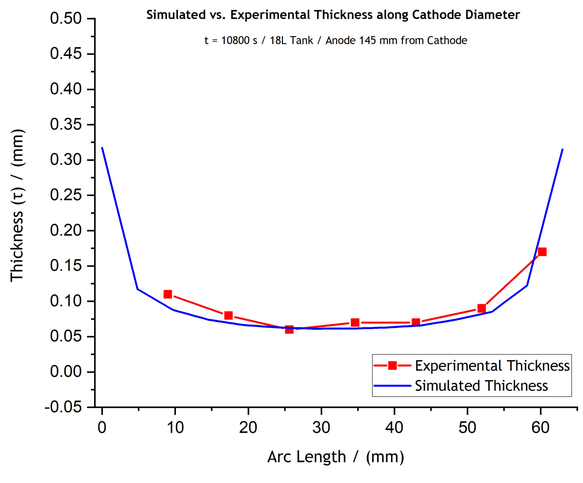
$$-i_s \cdot n = i_l \cdot n = \sum_m i_{loc,m}$$

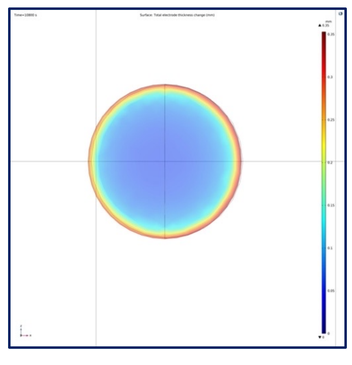
Declare the Physics

[Validation…]

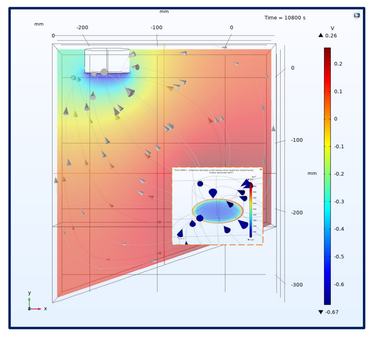


Scaled-up experimental thickness: ~0.07 mm
Scaled-up predicted thickness: ~0.075 mm





Thickness Distribution on the Cathode



Potential & Current Distribution Visualisation in the Electrolyte

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