Process Developments for Sustainable Electrochemical Machining

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Industry sponsor: Precision Tooling Services Ltd

Industry Challenge

The main aim is to enhance the capabilities of Electrochemical Machining (ECM) while overcoming its drawbacks so that a fully sustainable - in terms of production efficiency, resource consumption and waste generation - precision machining process is created for the industry. This will enable for the industry to align with the Scottish and UK Government's sustainable manufacturing strategies.

Objectives
Develop sustainable electrolytes addressing passivation and sludge generation.

Eliminate/reduce environment impact and toxicity of the by-products, such as converting hexavalent chromium into a benign form.

Optimize the process energy utilization and the process efficiency.

Facilitate environmental symbiosis by reclaiming the metal ions from the sludge.

Electrochemical Machining (ECM)

Electro-Chemical Machining (ECM), a form of reverse electroplating, is a "non-traditional" machining method that uses a shaped tool to produce a mirror image cavity on the workpiece. Unlike traditional machining, in ECM, the tool does not contact the workpiece, instead dissolves it atom by atom via electrolysis.

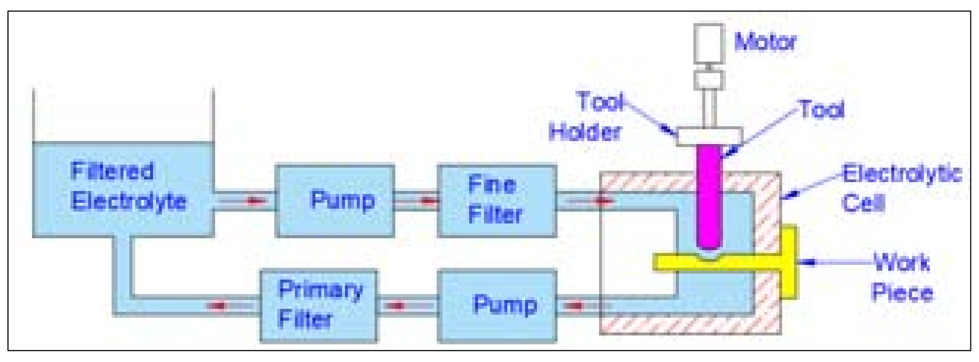

Fig 1 – Electrolyte flow in ECM [1]

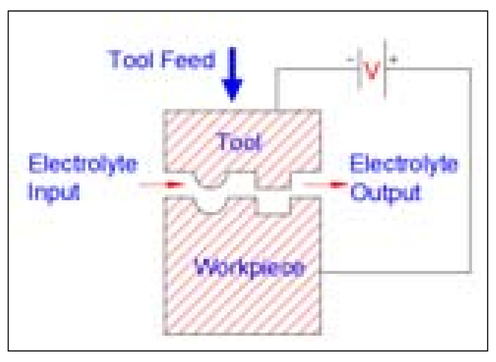

Fig 2 – ECM process [2]

What ECM can offer

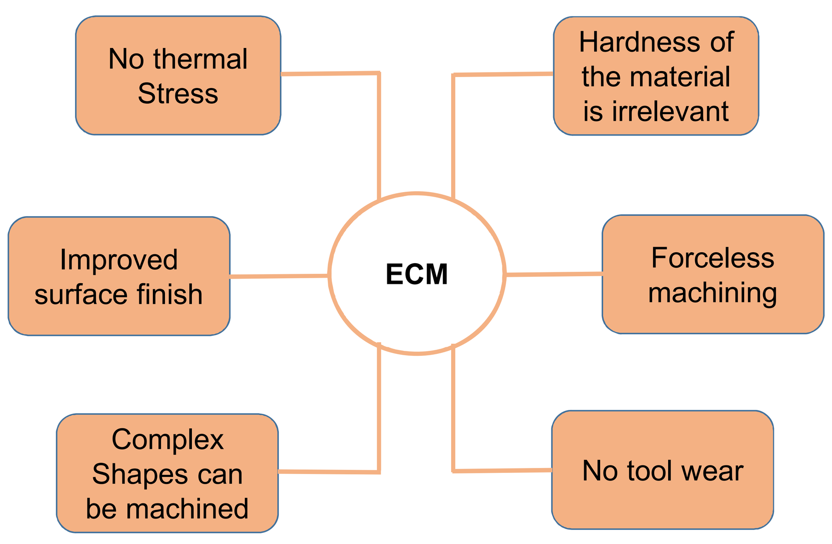

Fig 3 – Capabilities of ECM [3]

Drawbacks of ECM

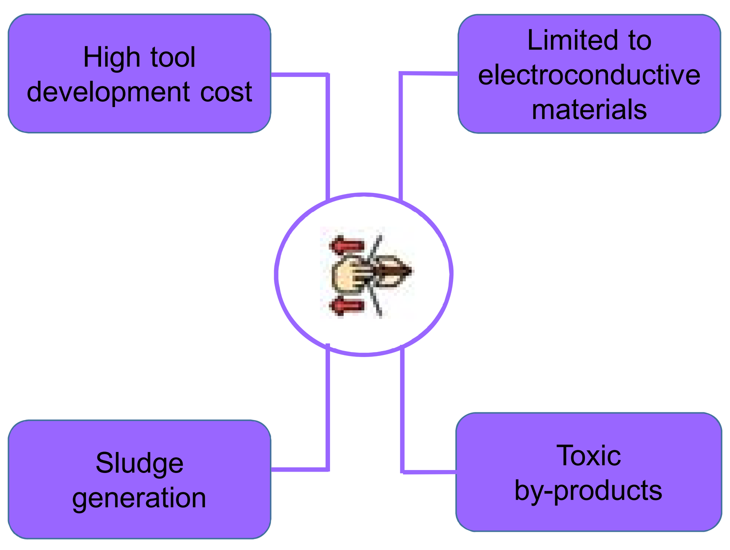

Fig 4 – General drawbacks of ECM [3]

Proposed Research

Fig 5 - ECM Machine used for the project [1]

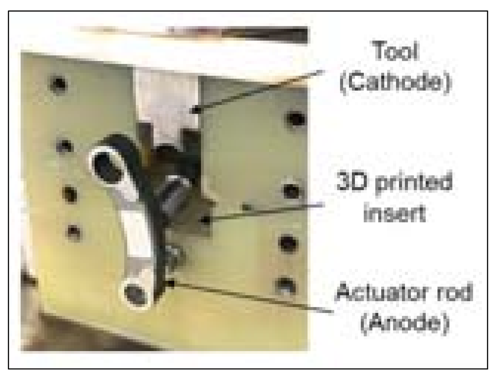

Fig 6 – Actuator rod in the cell [1]

Fig 7 – Actuator rod [1]

Industrial partner: The industrial partner provides precision machined components across a broad spectrum of technically demanding markets. Primary testing is done in an ECM testing facility provided by the industrial partner.

Value addition: The ECM knowledge base created will provide opportunities for the industry to expand and grow their business in advanced and environmentally sustainable manufacturing.

Example:
During ECM, elements of the workpiece dissolve in the electrolyte, making it harmful to both health and the environment.

The industrial partner uses an alloy (Tribaloy T-400) in the workpiece, generating chromium, cobalt, molybdenum, and nickel-based by-products in both the electrolyte and the sludge.

A treatment process was developed to remove dissolved by-products from the electrolyte.

Proposed process layout

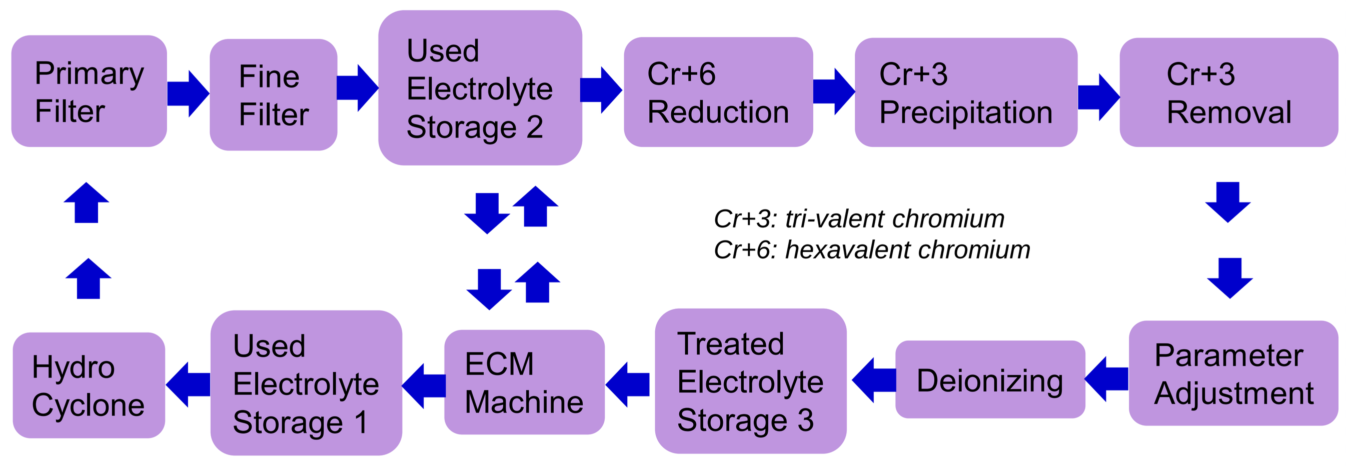

Fig 8 – Reduction of Hexavalent chromium

Result

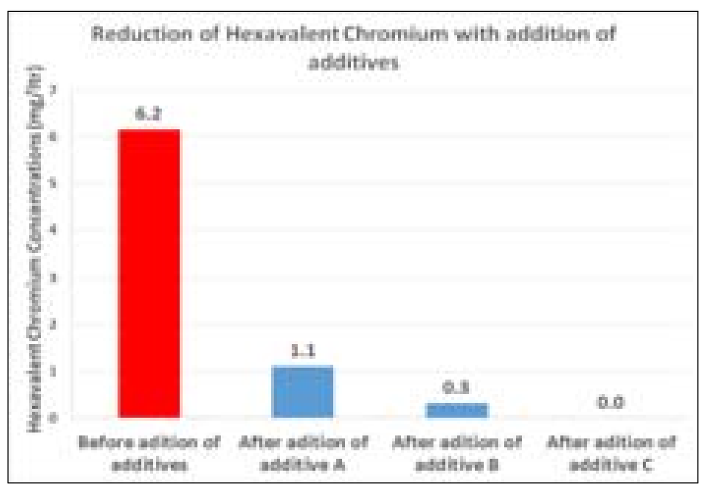

Fig 9 – Reduction of hexavalent chromium

Three chemical additives (A, B & C) were tested in order to convert carcinogenic hexavalent chromium into tri-valent chromium, which is the benign form of chromium.

Hexavalent chromium concentration of the waste Electrolyte was found to be 6.2mg/ltr.

Applicability of electrocoagulation, which is a water purification technology, was tested. However, it is slow and energy intensive process.

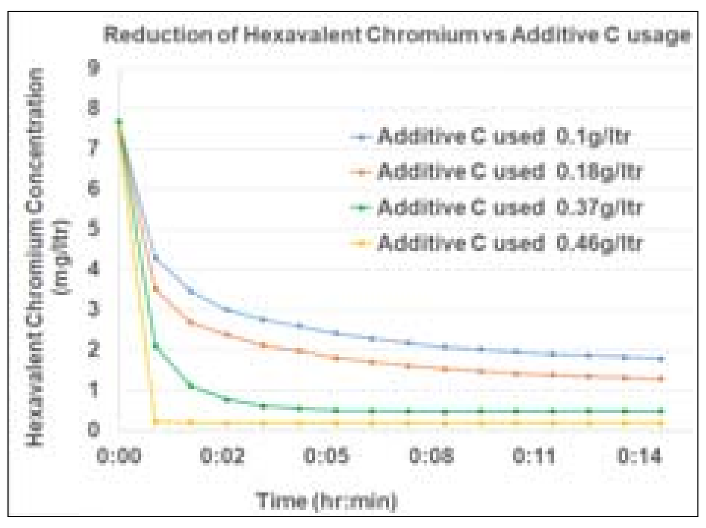

Fig 10 – Reduction of hexavalent chromium

Conversion rate of hexavalent chromium to tri-valent chromium by the addition of additive C was studied in detail.

1000ltrs of electrolyte can be treated for carcinogenic hexavalent chromium at a cost £10 to £15

The additive C itself also has no health or environmental hazards

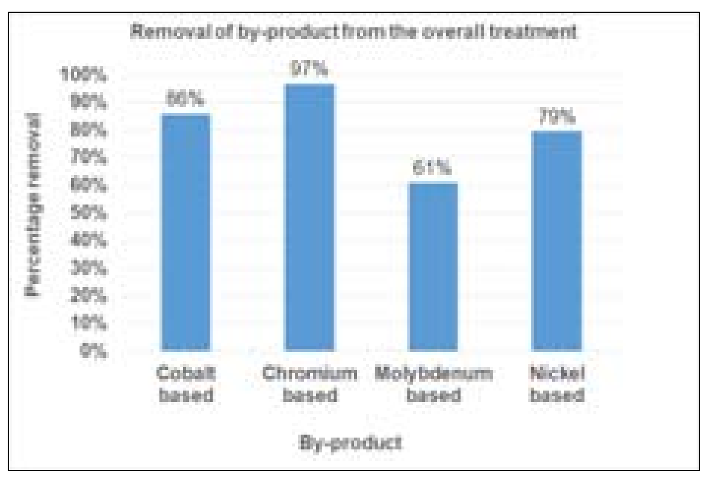

Fig 11 – Removal of by-products

The above additives are used to treat hexavalent chromium in the first stage of the treatment process

The second-stage treatment process was developed to remove cobalt, molybdenum, and nickel-based by-products from the electrolyte.

Trivalent chromium, converted from hexavalent chromium in the first stage of the treatment process, is also removed during the second stage.

Conclusion

Additives developed to reduce hexavalent chromium are efficient and economical.

Additive based electrolyte treatments give better results compared electrocoagulation.

The overall treatment process, which was developed to enhance the recyclability of the electrolyte, makes the ECM process more sustainable.

Next step

Application of industrial symbiosis as solution for sludge generation

References

[1] Precision Tooling Services Ltd – 2021
[2] M. Chai, Z. Li, H. Yan, and X. Sun, "Experimental investigations on aircraft blade cooling holes and CFD fluid analysis in electrochemical machining," Adv. Mater. Sci. Eng., vol. 2019, 2019, doi: 10.1155/2019/4219323.
[3] M. M. Lohrengel, K. P. Rataj, and T. Münninghoff, "Electrochemical Machining - Mechanisms of anodic dissolution," Electrochim. Acta, vol. 201, pp. 348–353, 2016, doi: 10.1016/j.electacta.2015.12.219.