Lecture 9

Modelling of the metal finishing technologies. Electroplating. Reaction kinetics.

Metal finishing refers to a family of technologies used to modify the surface of a metal object by depositing a thin metallic layer. The most common and industrially important process is electroplating, which relies on electrochemical deposition principles. Electroplating is used for: corrosion protection (e.g., Zn, Ni, Cr coatings); decorative finishes (gold, silver); functional coatings (wear resistance, conductivity); electronic and MEMS applications (Cu, Ni–P microstructures).

From Modelling Perspective

Electroplating involves complex coupled phenomena:

- Ionic transport in electrolyte,
- Electron transport in the substrate,
- Charge transfer reactions at the interface,
- Nucleation and growth on the surface,
- Hydrodynamics and flow patterns.

The goal of modelling is to quantitatively predict:

- Current and potential distribution,
- Deposition rate and uniformity,
- Thickness distribution,
- Surface morphology,
- Energy efficiency.

For example, model of decorative electroplating models a secondary current distribution with full Butler–Volmer kinetics for both anode and cathode. The thickness of the deposited layer at the cathode is computed along with the surface thickness change on the anode caused by metal dissolution. Each of these stages can be described using mathematical models, allowing prediction and control of the deposition rate, uniformity, and microstructure.

The model geometry is shown in Figure 1. The anode is a planar dissolving anode. The cathode represents a furniture fitting that is to be decorated by metal plating.

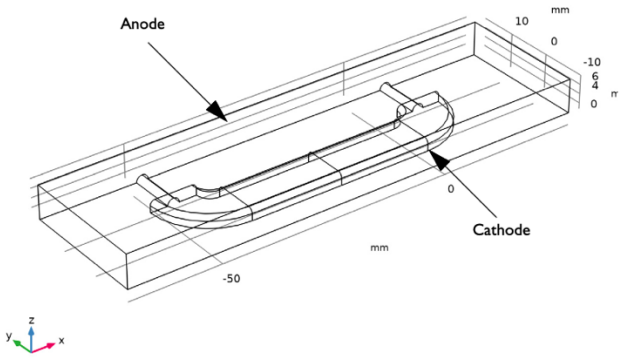

Figure 1: The model geometry.

The main electrode reaction on both the anode and the cathode surfaces is the nickel deposition/dissolution reaction according to

$$Ni^{2+} + 2e^- \leftrightarrows Ni_s$$

According to a Butler–Volmer expression the local current density sets as following:

$$j_{loc,Ni} = j_{0,Ni}\left(exp\left(\frac{\alpha_a F \eta_{Ni}}{RT}\right) - exp\left(\frac{-\alpha_c F \eta_{Ni}}{RT}\right)\right)$$

The rate of deposition at the cathode boundary surfaces and the rate of dissolution at the anode boundary surface, with a velocity in the normal direction, v (m/s), is calculated according to

$$v = \frac{j_{loc,Ni} M}{nF\rho}$$

where M is the mean molar mass (59 g/mol) and ρ is the density (8900 kg/m^3) of the nickel atoms and **n** is number of participating electrons. Note that the local current density is positive at the anode surface and negative at the cathode surfaces.

Figure 2 shows the change in the total electrode thickness for the cathode surfaces indicating the deposition thickness after 600 s. It can be seen that the deposition thickness is quite nonuniform. The lowest deposition thickness is found at the bottom end of the cathode geometry, farthest from the anode surface. The deposition thickness could be optimized further by changing design parameters such as plating cell geometry, distance between the anode and cathode surface, conductivity of the electrolyte and operational parameters such as applied current or potential.

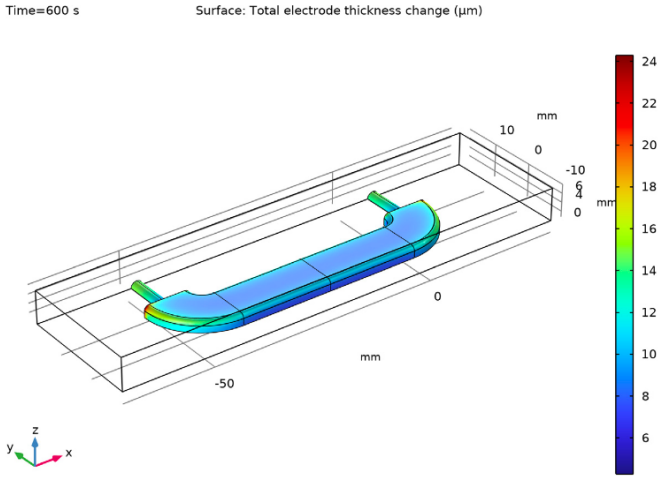

Figure 2: The simulated results of the change in the total electrode thickness [1].

Reference

1. COMSOL Multiphysics. Application Library path: Electrodeposition_Module/ Tutorials/decorative_plating