Transient Simulation of the Removal Process in Plasma Electrolytic Polishing of Stainless Steel

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1. Introduction

Plasma electrolytic polishing:

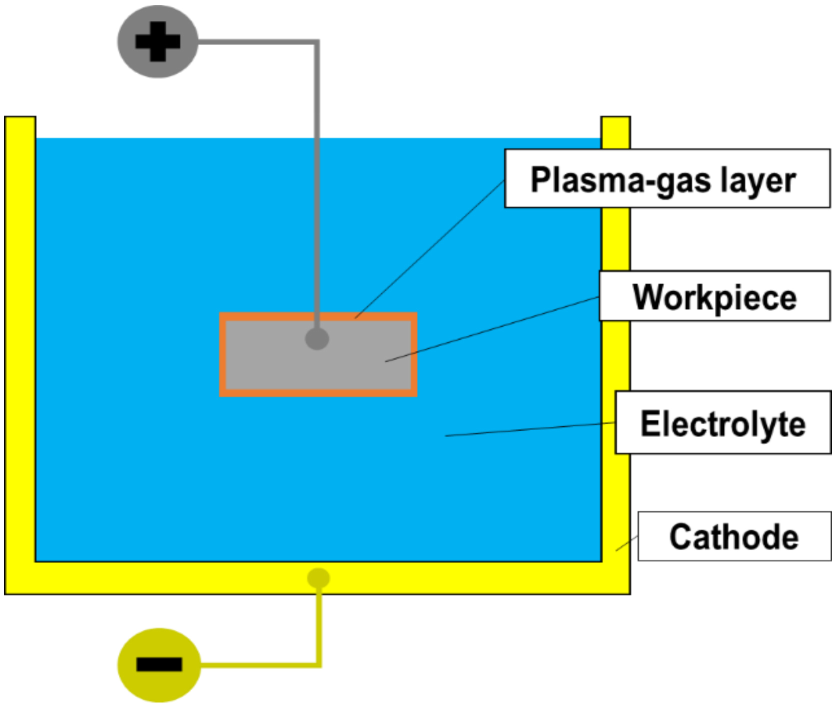
- Electrochemical method for surface treatment
- Special case of anodic dissolution [1]

Advantages:

- Environment friendly aqueous solutions of salts
- Small achievable roughness (Ra < 0.02 µm)
- Small removal rates
- Small processing times

Disadvantages:

- Mainly metal parts can be polished
- Energy source determines the maximum part size
- Each metal requires electrolyte adaption



Principle scheme of PeP

1. Introduction

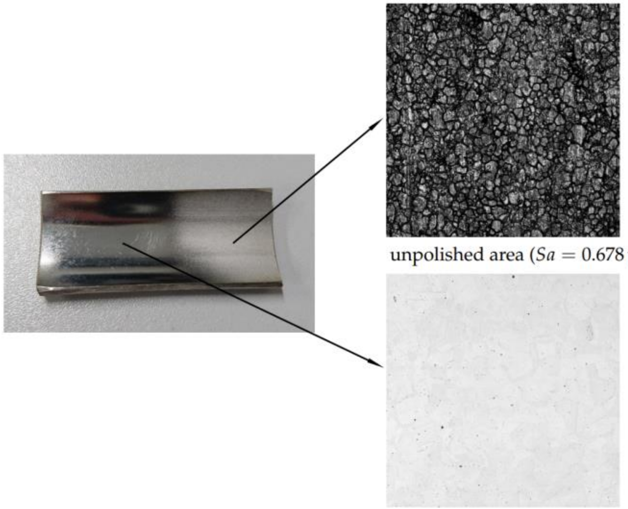
Challenges:

- Few research work has been focused on the understanding of the process and even less on simulation
- Complex combination of many physical phenomena
- The mechanism of the polishing process is not fully understood yet

Objectives:

- Investigate PeP process:
  - Potential distribution
  - Current density distribution near the workpiece surface
- Simulate polishing process during PeP

Partially plasma electrolytic polished CoCr knee cap [2]



Polished steel pipe [3]

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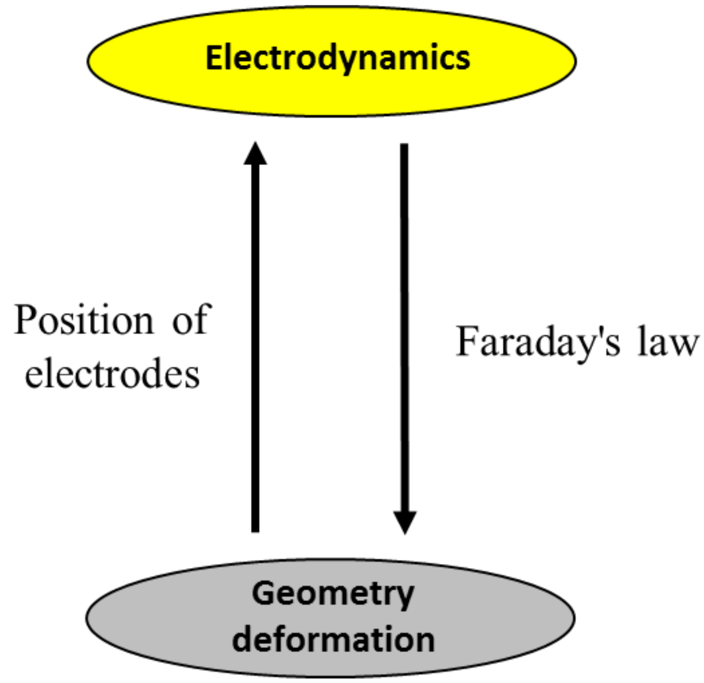
2. Model description – Studies and couplings

- The model is based on the assumption that PeP can be considered as an electrochemical polishing
- The simulation has two studies: stationary study and time-dependent study
- Geometry deformation is function of normal current density on the surface

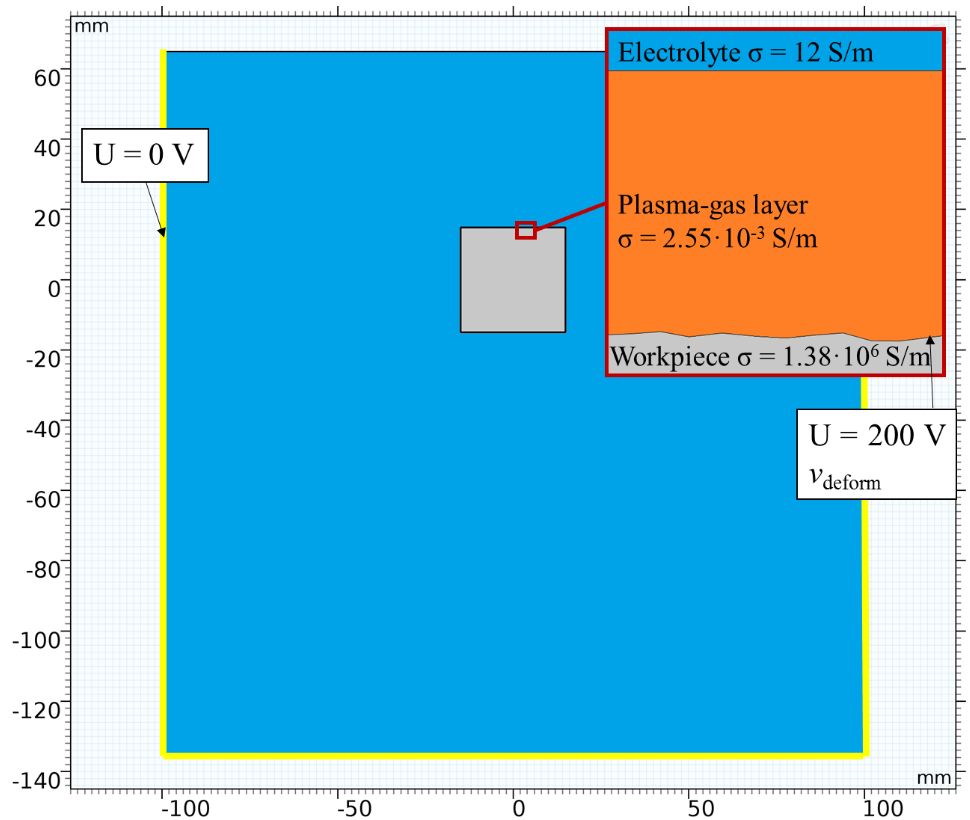
$$v_{\mathrm{deform}} = K \cdot (-j_n)$$



Coupling scheme of the multiphysical model

2. Model description – Initial geometry and boundary conditions

- Ammonium sulfate in concentration of 50 g/l as an electrolyte [4]
- Steel 304 as material for the workpiece
- The thickness of plasma-gas is 150 µm
- Applied voltage of 200 V
- The initial anode surface profile was generated in COMSOL Multiphysics® using Spatial Frequencies method [5]



Modell geometry and boundary & domain conditions

2. Model description – Plasma-gas layer conductivity and removal coefficient

- Based on the assumption, that almost all voltage drops in the plasma-gas layer
- Electrical field of $1.3 \cdot 10^4$ V/cm corresponds to values provided in literature: 10^4 V/cm - 10^5 V/cm [6-8]
- Removal coefficient K is calculated from experimental data : average material removal rate (MRR) and average current density for 200 V [4]

$$E = \frac{V}{h} = \frac{200\ \mathrm{V}}{0.015\ \mathrm{cm}} = 13333\ \ \mathrm{V/cm}$$

$$j_n = \sigma \cdot E$$

$$\sigma_{plasma-gas} = \frac{j_n}{E} = \frac{0.3399\ \ \mathrm{A/cm^2}}{13333\ \mathrm{V/cm}} = 2.55 \cdot 10^{-2}\ \mathrm{mS/cm}$$

$$K = \frac{MRR}{j_n} = \frac{5.24 \cdot 10^{-8}\ \ \mathrm{m/s}}{3398.69\ \ \mathrm{A/m^2}} = 1.54 \cdot 10^{-11}\ \mathrm{m^3/(A \cdot s)}$$

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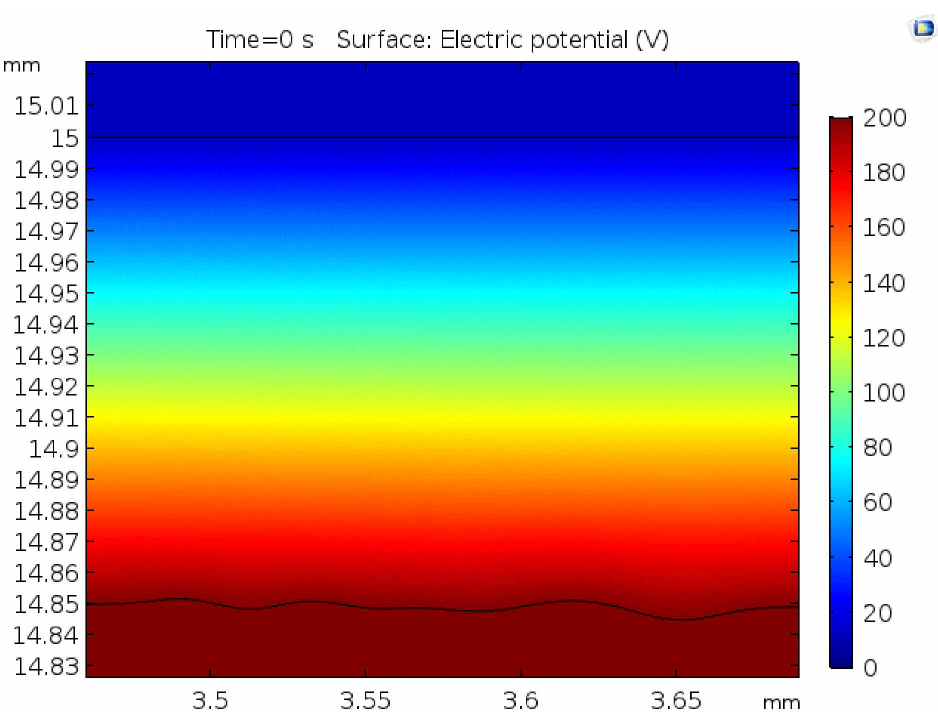
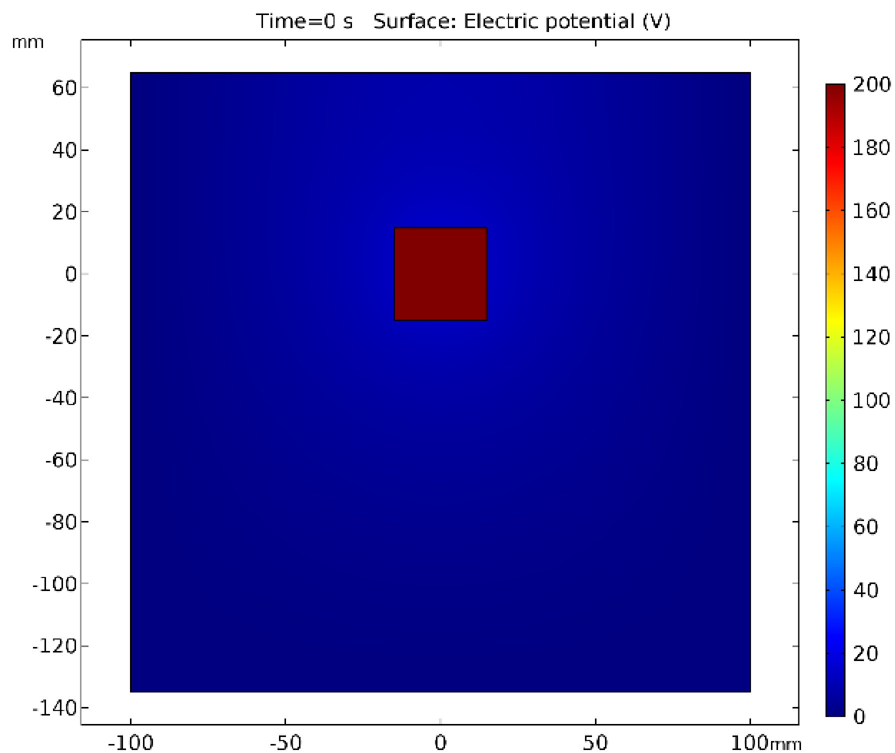
3. Results – Polishing effect and electric potential



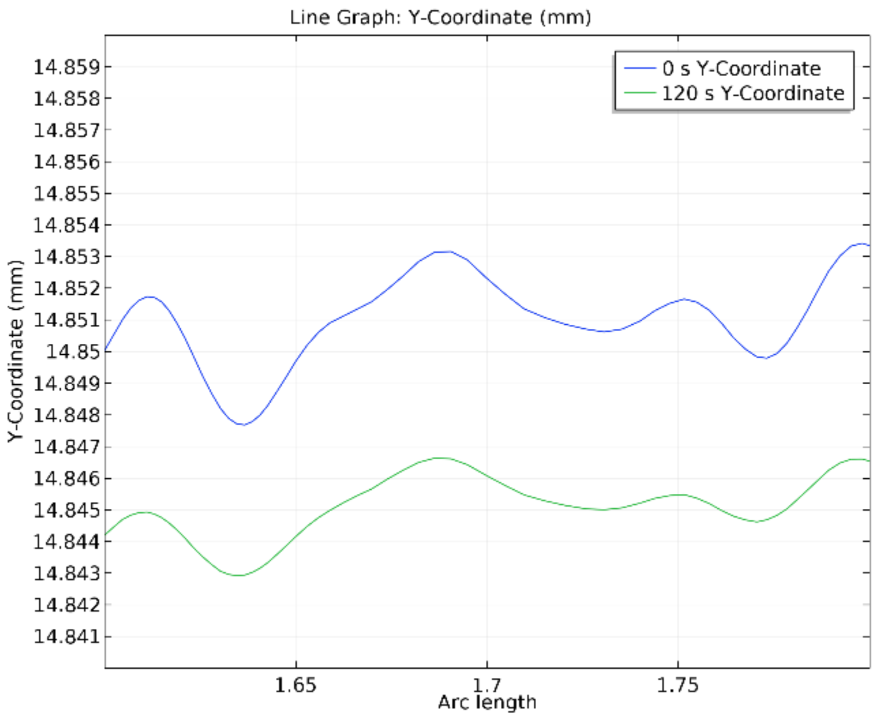
Animation of the polishing process



Electric potential

3. Results – Polishing effect and electric potential

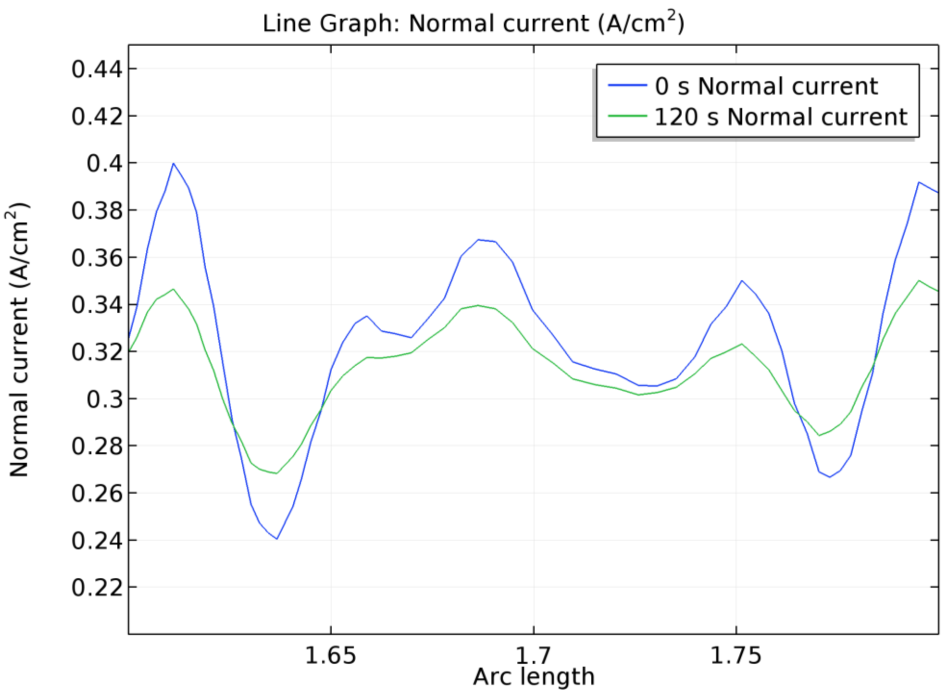
- The main voltage drop occurs in in the plasma-gas layer
- Despite the fact that the overall shape of the surface is conserved, the peaks were removed more
- Because of voltage drops in plasma-gas layer, it can be considered as a special electrochemical cell, where the interface between plasma-gas layer and electrolyte acts as a cathode



Surface profile at 0 s and 120 s

3. Results – Current density during polishing

- The normal current density in the cavities is lower than at the peaks
- The current density at the deeper cavities increases with the processing time
- Average current density in model is 0.313 A/cm^2 comparing to 0.340 A/cm^2 in experiment [4]



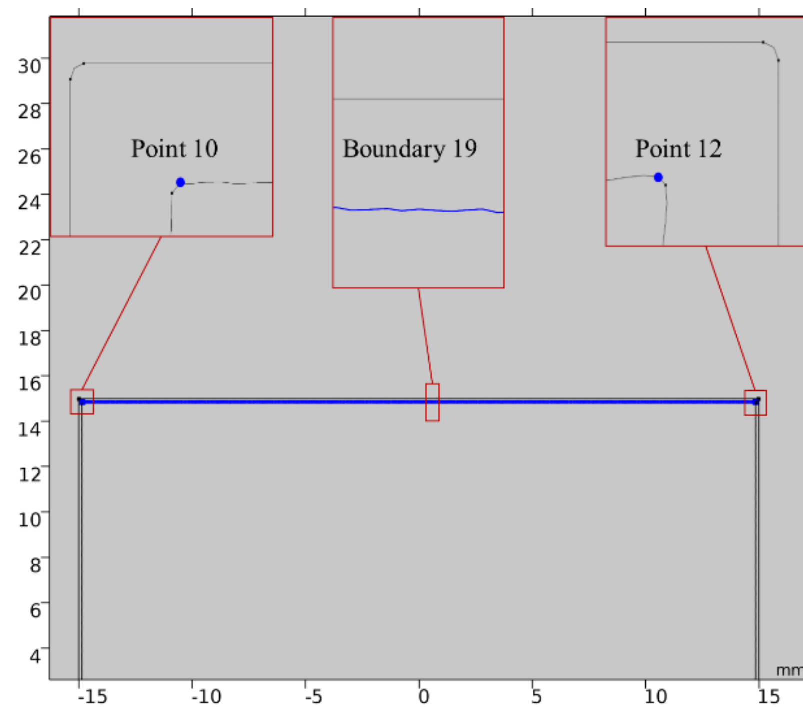
Normal current density at 0 s and 120 s

3. Results – Roughness calculation

- To analyse the polishing effect, the roughness parameter Ra was calculated based on:

$$Ra = \frac{1}{l}\int_0^l |h(x)|\,dx$$

- Next component couplings were used:
  intop1 - integration over a boundary 19;
  p10 and p12 - maximum functions in points 10 and 12 respectively;
  aveop1 – average over a boundary 19



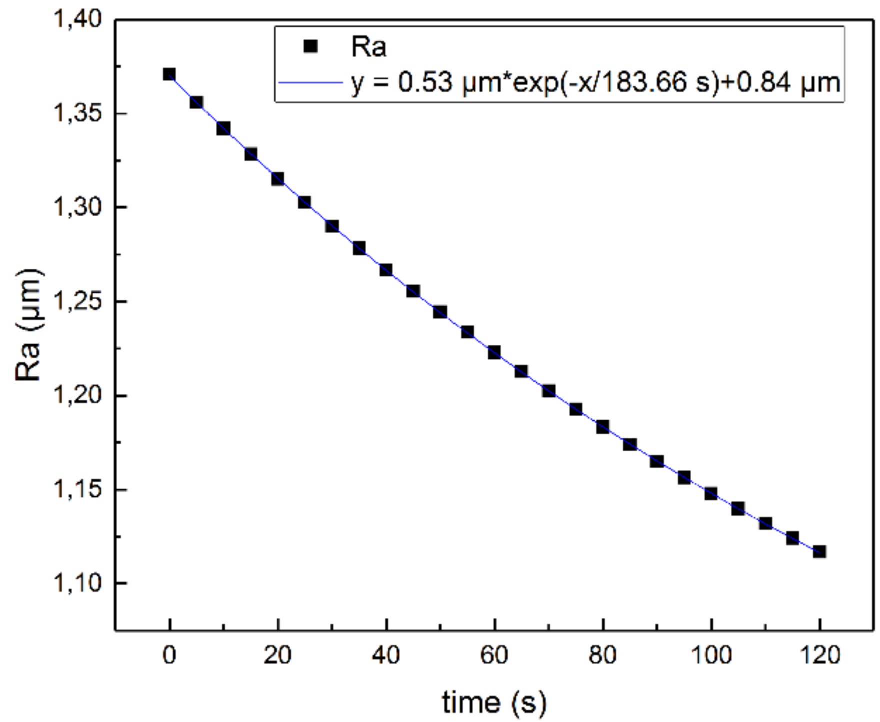
Boundary and points used in couplings

3. Results – Roughness calculation

- Equation used in the model for Ra calculation

$$Ra = \frac{1}{(p12(x) - p10(x))} \int_{p10}^{p12} |y - \bar{y}| \, dx$$

- The roughness decreases in the model according to exponential decay, what corresponds to real experimental data [7]
- The minimal achievable roughness Ra in this model based on the exponential fit has a value of 0.84 µm [7]



Selected results for Ra as function of time with fit curve

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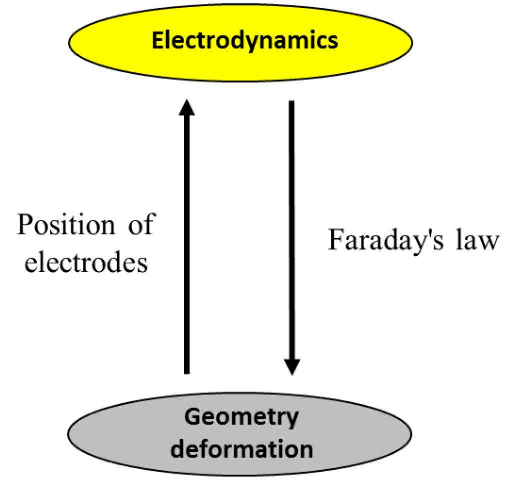
4. Summary

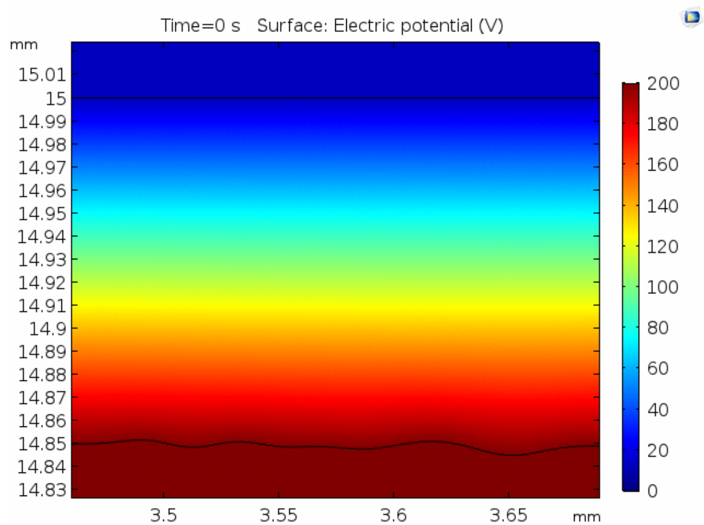
- 2D simulation of the plasma electrolytic polishing
- PeP of stainless steel can be simulated as an electrochemical machining process
- Simulation of the polishing effect and removal process
- Implementation of Ra calculation in the model

Next steps:

- Longer simulated time
- Comparison with experimental data
- Simulation with initial roughness from real sample



Coupling scheme of the multiphysical model



Animation of the polishing process

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Thank you for your attention

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