2-D Axisymmetric Simulation of the Electrochemical Machining of Internal Precision Geometries

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Results

- Performing removal simulation up to electrochemical machining time of t = 250 s regarding interactions between fluid-, thermo-, electro-dynamics and formation of hydrogen
- Simplification of fluid dynamics by modeling fluid flow using potential flow simulation (**Fig. 1**) → Maximum velocity at the entrance of the working gap u_{max} = 25.6 m/s
- Joule heating during machining process (**Fig. 2**) → Electrolyte is heated from 20 °C at the entrance of the working gap to 27 °C at the exit; workpiece surface is heated up to 36.3 °C
- Formation of hydrogen at cathode surface (**Fig. 3**) → At the working gap exit up to 40 % of the electrolyte volume is hydrogen
- Resulting electrical conductivity of electrolyte (**Fig. 4**) → High temperature areas leads to increased electrolyte conductivity up to 9.95 S/m and high volume concentration of hydrogen decreases electrical conductivity to 4.99 S/m
- Leads to electric current density distribution within the electrolyte (**Fig. 5**) and normal electric current density on workpiece surface (**Fig. 6**) → Shaping internal bore within the lateral gap up to L = 19.2 mm

Model creation

- Derivation of a 2-D axisymmetric model from the nearly cylindrical design concept (**Fig. 7 & Fig. 8**) of electrochemical machining process:
  - Outer workpiece diameter 44 mm
  - Pre-drilled bore diameter 25 mm
  - Cylindrical cathode disk diameter 31.6 mm

Allocation of material parameters				
Domain	**Material**	σ **[S/m]**	λ **[W/(m·K)]**	c_p **[J/(kg·K)]**
I	Electrolyte	$\sigma_{eff}(\phi_{El}, T)$	0.599	3877
II, VI	SAM 10	$1.69 \cdot 10^6$	21.5	410
III	1.4301	$1.37 \cdot 10^6$	15	500
IV, V	POM	10^{-10}	0.31	1500

- Effective electrical conductivity of electrolyte influenced by temperature and produced hydrogen gas volume

$$\sigma_{\mathrm{eff}}(\phi_{\mathrm{El}}, T) = \left(1.646\,\frac{\mathrm{mS}}{\mathrm{cm}}\left(\frac{T}{1\mathrm{K}} - 273.15\right) + 39.796\,\frac{\mathrm{mS}}{\mathrm{cm}}\right) \cdot \phi_{\mathrm{El}}^{\frac{3}{2}}$$

- Implementing experimental determined material-specific removal velocity function v_a for simulating material dissolution on workpiece surface (**Fig. 9**)

$$v_{a,c_1}(\hat{J}_n) = \begin{cases} 0\,\frac{\mathrm{mm}}{\mathrm{min}} & \text{for } \hat{J}_n < 11\,\frac{\mathrm{A}}{\mathrm{cm}^2} \\ \left(0{,}0123\,\frac{\mathrm{cm}^2}{\mathrm{A}} \cdot \hat{J}_n - 0{,}1353\right)\frac{\mathrm{mm}}{\mathrm{min}} & \text{for } \hat{J}_n \geq 11\,\frac{\mathrm{A}}{\mathrm{cm}^2} \end{cases}$$

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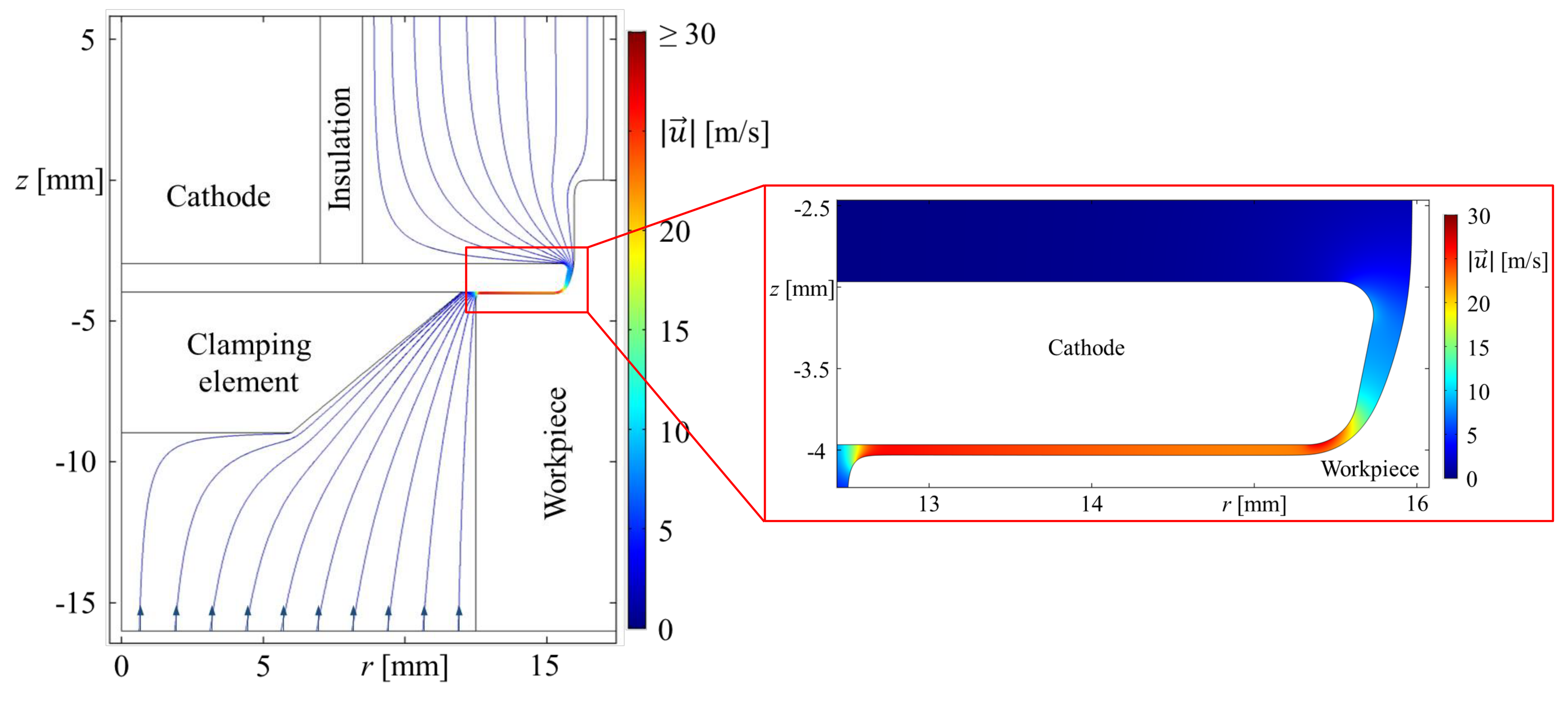

Figure 1. Field of fluid velocity as streamline false color rendering and detailed view of the working gap at t = 250 s

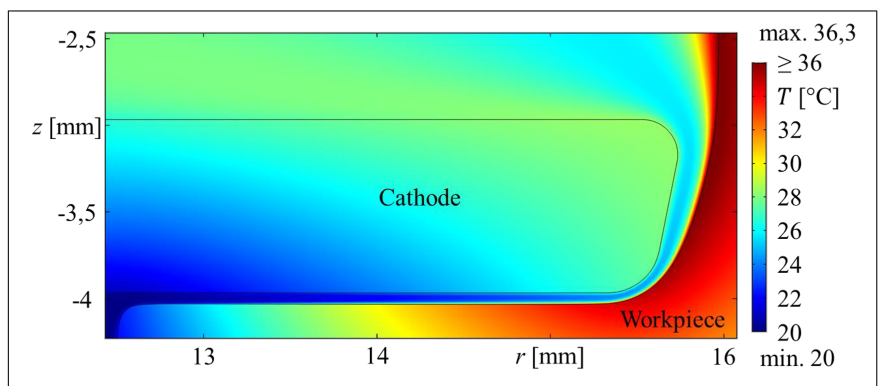

Figure 2. Temperature field

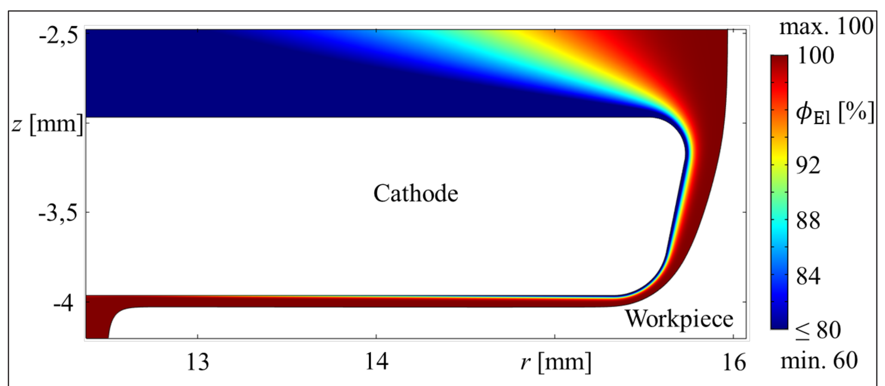

Figure 3. Volume concentration of electrolyte

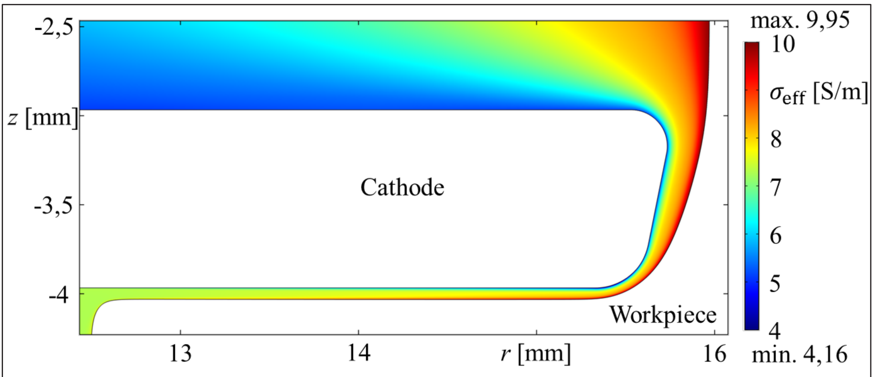

Figure 4. Electrical conductivity field

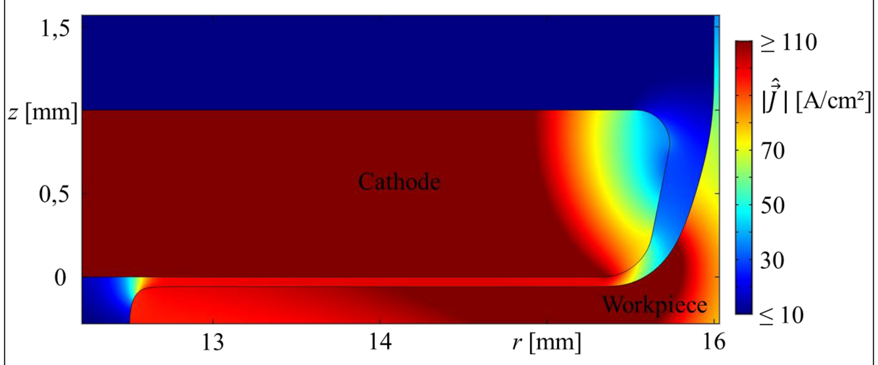

Figure 5. Electrical current density field

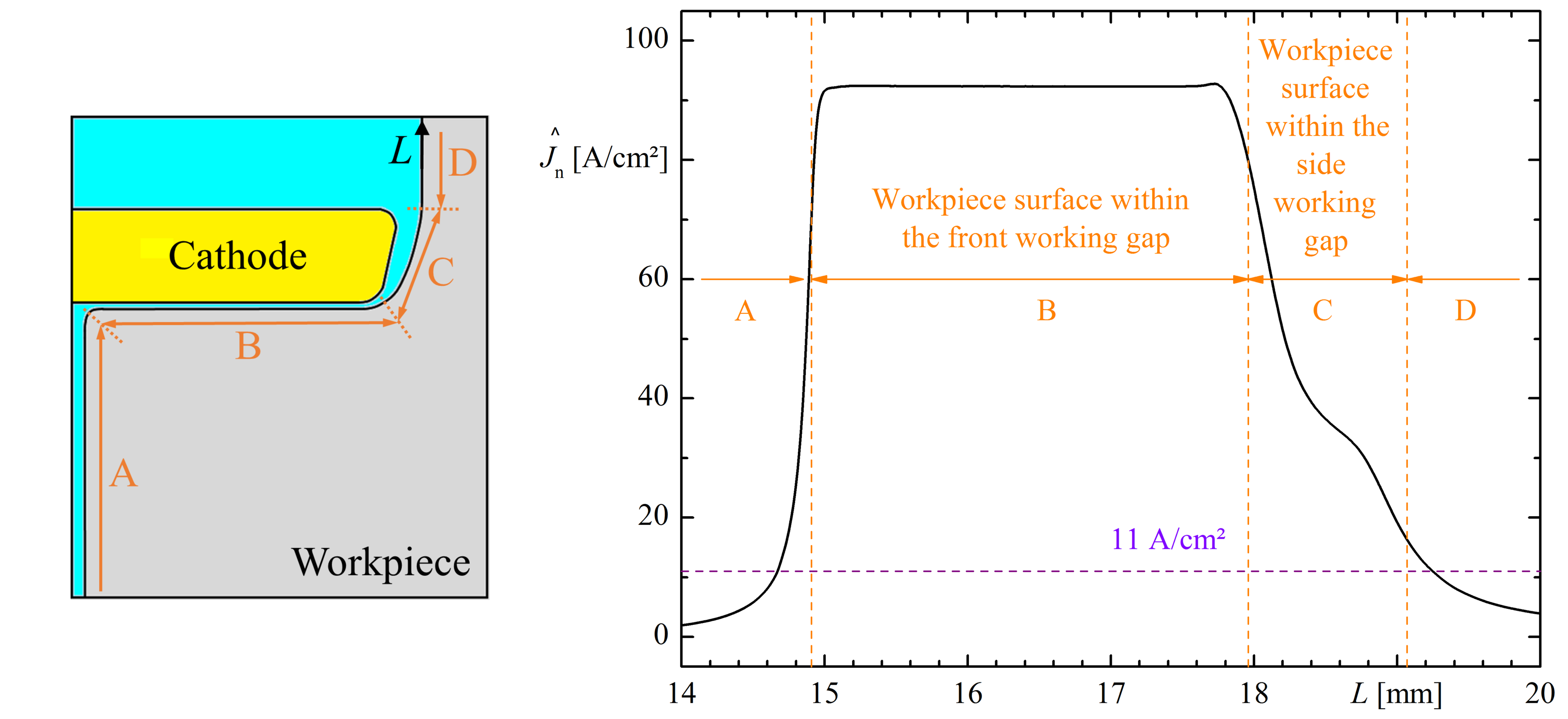

Figure 6. Resulting current density along the workpiece surface as a function of the arc length L

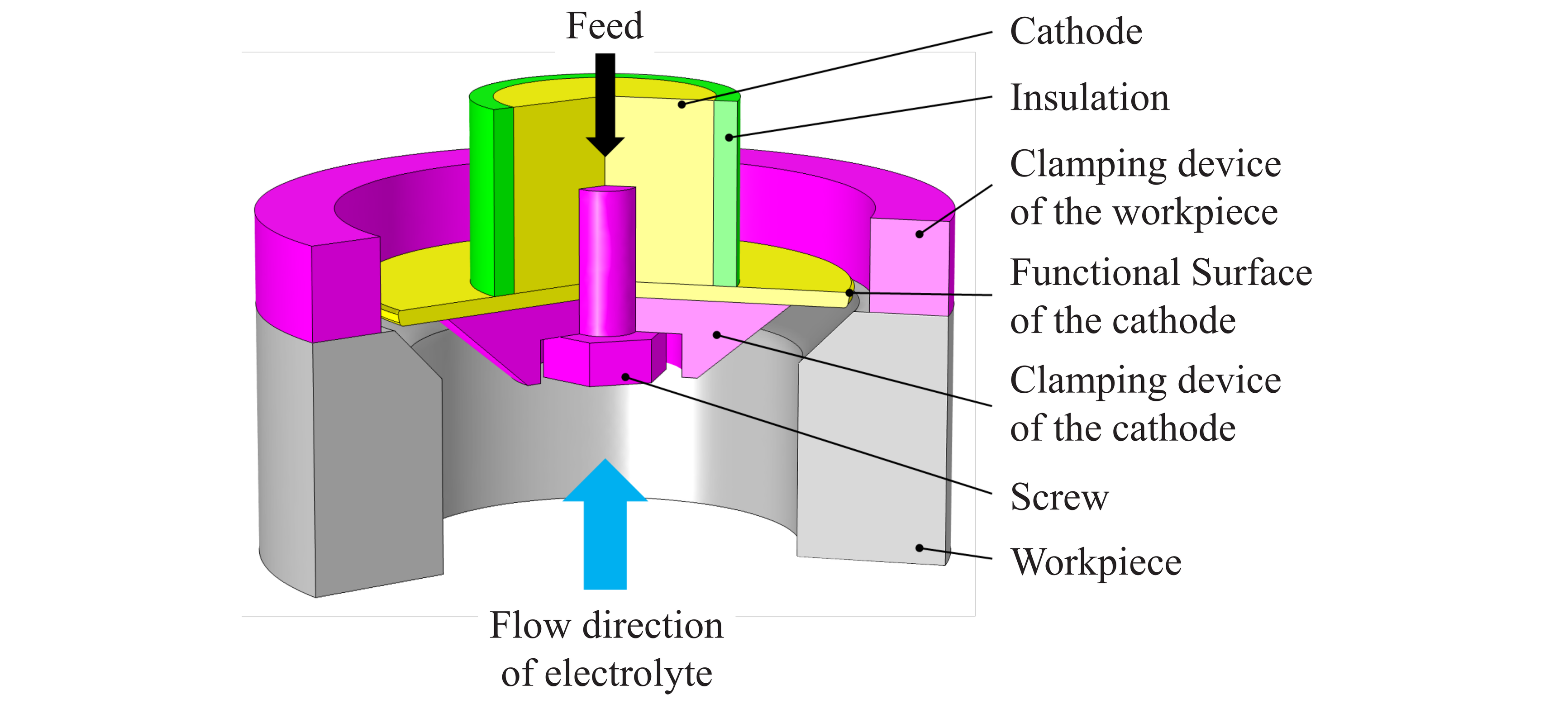

Figure 7. Design concept for machining internal precision geometries with electrochemical machining

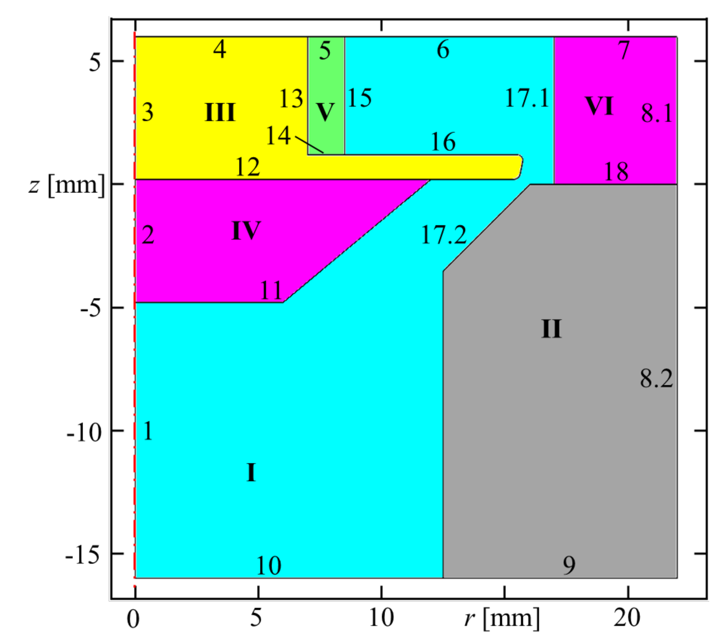

Figure 8. Initial 2-D axisymmetric geometry of the model

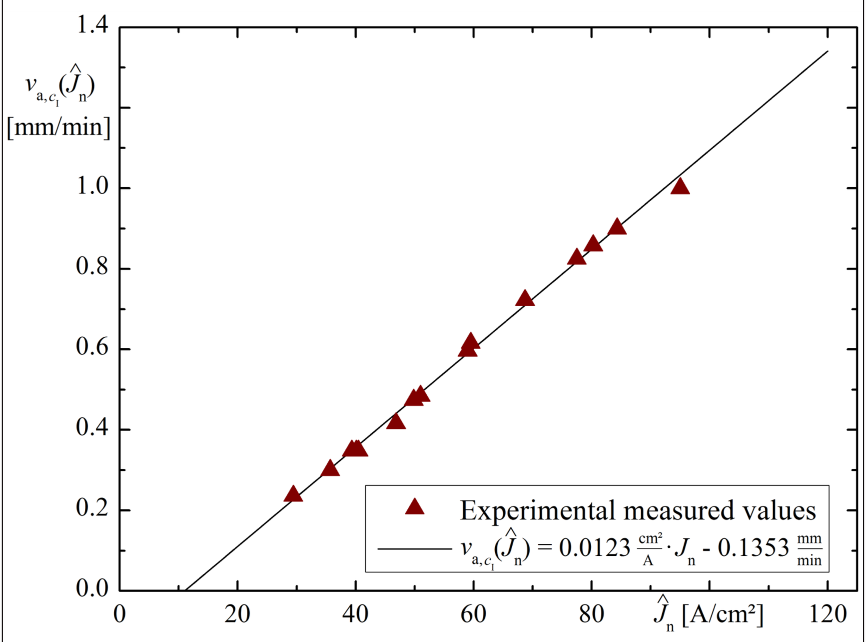

Figure 9. Material-specific removal velocity in z-direction v_a of SAM 10 as function of normal current density J_n

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