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Investigation of the Electrodeposition Parameters on the Coating Process on Open Porous Media

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Porous materials such as bones, sponges or cork are used in nature due to their light weight. Metal foams with stochastically distributed pores are such a porous bionic material based on nature. Their low weight and mechanical properties make them perfect for use in aerospace, automotive and building construction industry. To improve the mechanical properties, hybrid metal foams are produced consisting of a substrate foam with a coating applied by electrodeposition. An electrochemical coating cell consists of a positively charged anode and a negatively charged cathode. The metal of the anode is oxidised to a positively charged cation and electrons. The cation moves through the electrolyte to the cathode, where it is reduced back to the metal and electrons are consumed. Due to this process the cathode is coated with the anode material. The mass transport during the electroplating process can be divided into four parts: Convection, diffusion, migration and reaction. Convection is a forced flow, e.g. by pumping. Diffusion describes the movement caused by concentration gradients and the migration is the movement by an electric field. Reaction is the ion consumption at the cathode during the electrodeposition process and is therefore called sink. During the electrodeposition process, coating thickness inhomogeneities occur due to mass transport limitations [2, 4] and lead to non-uniform mechanical properties within the coated foams. These inhomogeneties motivate an investigation of the electrodeposition process and its parameters.

1 Modelling and Simulation

The Nernst-Planck equation is the model approach to describe the electrodeposition process for convection, diffusion and migration with a reaction part, which is linearly dependent on the concentration of the cations c,

$$\frac{\partial c}{\partial t} = \nabla\left(c\,\mathbf{u} - D\,\nabla c - \frac{z\,F}{R\,T}\,c\,\nabla\phi\right) + a_0 c\,, \tag{1}$$

were $\mathbf{u} = u_0\,\mathbf{I}$ is the velocity, D the diffusivity, z the valence of ionic species, F the Faraday constant, T the temperature, R the gas constant, ϕ the electric potential and $a_0 c$ the reaction part, which is in this case the sink part with the sink constant a_0. The electrodeposition process was simulated with the values shown inTtable 1 using finite differences. The implementation of convection and migration was done by a first order upwind scheme, the implementation of diffusion with a central difference quotient. For the boundary conditions, in the first time-step the concentration was assumed to be constant with $100\,g/l$ over the complete foam, in all further time-steps the concentration was kept constant at $100\,g/l$ only at the outer foam surface and the values inside the foam were calculated during the simulation. The velocity of the electrolyte refers to a movement in positive x-direction (Fig. 1). The simulated foam has a size of $0.4 \times 0.4 \times 0.4\,m^3$, but due to symmetry it was only simulated in two dimensions x and y and as third dimension the time t. Fig. 2 shows the concentration distribution in x-direction as function of time.

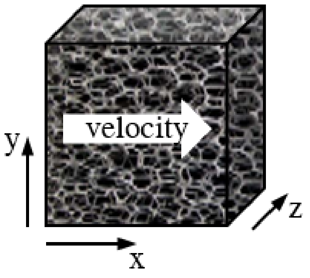

Fig. 1: Direction of velocity in x-direction.

variable	value
c	$100\,g/l$
D	$1.2 \times 10^{-9}\,m^2/s$
T	$40\,°C$
z	2
t	$200\,s$
u_0	$1\,l/min$
a_0	$0.07\,g/m^2s^2$
φ	$1\,V/m$

Table 1: Electrodeposition parameters used for simulation.

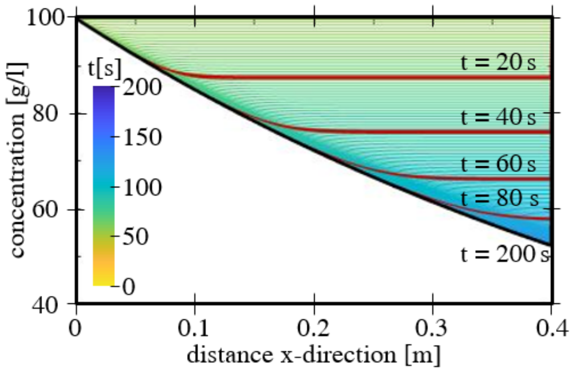

Fig. 2: Concentration distribution during the electrodeposition process for each time step over x-direction.

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The ion concentration decreases over time until it converge to steady-state, where the ion concentration stays constant. In the following, only the ion distribution in the steady state is considered.

2 Parameter Variation

To study the strength of the influence of the parameters velocity u_0 and sink constant a_0 the ratio λ of these parameters is introduced

$$\lambda = \frac{u_0}{a_0}\,. \tag{2}$$

u_0 and a_0 have the greatest influence on the concentration distribution, so it is sufficient to investigate these parameters [1]. First, the concentration distribution was investigated as a function of λ. λ is varied in the range $0.08\,u_0/a_0$ to $2.0\,u_0/a_0$, whereby the value $\lambda = 1.0\,u_0/a_0$ corresponds to the ratio of velocity to sink constant used for simulation of Fig. 2. λ changes with a change of u_0 or a_0, consequently both parameters are varied for each value of λ (Fig. 3). Overall, the concentration homogeneity decreases with decreasing λ. If the variation of λ is done by a change of the velocity, the electrolyte has a concentration of at least $25\,g/l$. If the sink constant is changed for the variation of λ, the concentration drops to $0\,g/l$.
Fig. 3 also shows that an increase in the sink constant reduces the concentration and a decrease in the velocity increases the concentration. Velocity and deposition parameters therefore have the opposite effect on the concentration homogeneity.
To study the concentration distribution at $\lambda = 1.0\,u_0/a_0$ with different values of velocity and deposition parameters, both parameters are equaly changed. The larger this factor is selected, the more homogeneous is the concentration distribution over the foam. If the factor is small, the concentration distribution runs into a steady-state and does not change anymore.

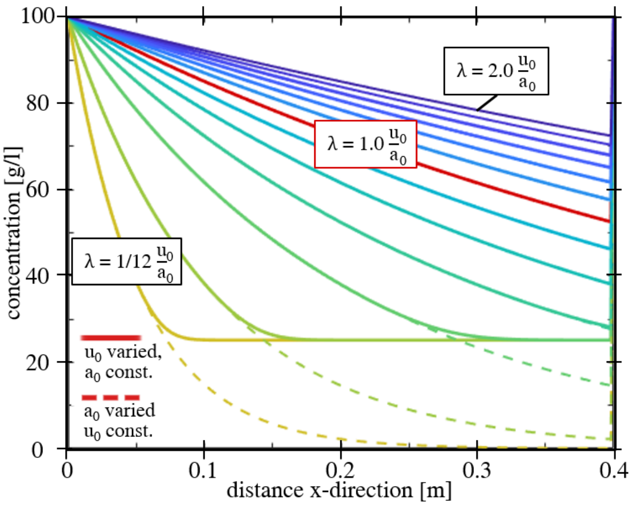

Fig. 3: Influence of the ratio of velocity to sink constant on the concentration distribution over the foam.

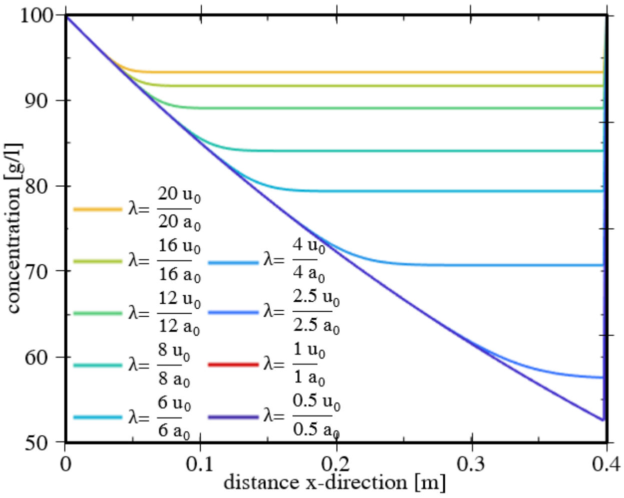

Fig. 4: Variation of velocity value and sink constant value to get a constant λ with $\lambda = u_0/a_0$

3 Conclusion and future work

Velocity and sink constant have a great influence on the concentration and thus also on the coating thickness distribution of metal foams. With an increasing ratio λ between velocity and sink constant the coating homogeneity increases over the foam. During the electrodeposition process, the coating of the foam alters its geometry and thus the electrical shielding and tortuosity of the foam. The electrical shielding affects the sink constant and the tortuosity affects the velocity across the foam. Due to the large influence of the sink constant and the velocity on the electrodeposition process, a fully-coupling has to be considered in the future.

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