Current working practice for the risk analysis of the damage by galvanic corrosion relies on tabulated values of open circuit potentials, the calculation of surface areas of the metals and is largely based on the experience. In this paper a computational simulation of corrosion attack of the constructions that are exposed to the thin film of electrolyte is presented. Theoretical basis of used anode. It is oxidized, the dissolution is promoted and the metal and conductively connected, the metal with the lower OCP acts as electrolyte. If two dissimilar metals are immersed into the electrolyte (OCP) is specific for given combination of the metal and the electrical potential against the electrolyte. This open circuit potential, given besides their OCPs by areas of their surfaces. The areas influence the current density. Between the electrodes flows the corrosion current. OCPs describe the thermodynamics and the polarization curves describe the kinetics of galvanic corrosion.

The evaluation of corrosion is possible in many different ways. Visual evaluation is possible e.g. according to international standard ČSN EN ISO 10289. Quantitative criterion for the evaluation is the mass loss rate and the corrosion rate. In the case of galvanic corrosion this values are connected with the density of corrosion current through the Faraday’s law:

$$m = k \cdot q$$  \hspace{1cm} (1)

where m is the mass of dissolved metal, k is a factor specific for each metal and q is an electric charge passed through the electrode/electrolyte interface.

### 3. Thin film

The thin film of electrolyte relates to a situation when the thickness of the electrolyte is much smaller in comparison with a characteristic dimension of the solved problem. Typical example of thin film electrolyte is condensation of moisture or rainfalls running off the constructions. In the bulk electrolyte, corrosion potential is a clear value. Resistance of the thin film has an impact on the thin film electrolyte. Flowing corrosion current causes an unequal distribution of the electrolyte electric potential along the surface of the electrodes. In this paper, software BEASY Corrosion Manager (http://www. beasy.com) is used for evaluation of some common structural details. This programme uses BEM approach, as corrosion is a matter of a surface of materials. Analysis of an electrolyte volume is simplified as mentioned below. Physical and mathematical background of the programme is as follows [Palani 2011].

Schematic depiction of galvanic corrosion under the thin film is in Fig. 1:

![Schematic depiction of galvanic corrosion under the thin film](image)
Ve(x) is the electric potential in the electrolyte at point x. The boundary conditions for insulating surfaces are

\[ \text{must be contained in input data for the simulation.} \]

These polarization curves are described by the corresponding polarization curve for the metal of the anode and of the cathode respectively. These polarization curves must be contained in input data for the simulation.

The boundary conditions for insulating surfaces are \( j_n = 0 \).

In general, it is necessary to solve this problem in 3D. But if the thickness of the electrolyte \( w \) is much smaller than a characteristic dimension of the problem \( L \) (see Fig. 1), the electrical potential \( V_e \) can be considered as constant in \( z \) direction. This behaviour allows excluding the \( \frac{\partial}{\partial z} \) component from the mathematical formulation of the problem by direct integration of it along the thickness \( w \) and the eq. 2 changes into:

\[
\nabla \cdot \left(-\sigma \nabla V_{e_{2D}}\right) = -j_f \Delta V
\]

where \( j_f \) is the current density flowing through the surface in normal direction and \( \Delta V \) is the polarization potential across the electrode/electrolyte interface. Polarization potential is given by \( \Delta V = V_e - V_m \) where \( V_m \) is the potential of the metal. This boundary condition is described by the corresponding polarization curve for the metal of the anode and of the cathode respectively. These polarization curves must be contained in input data for the simulation.

The boundary conditions for insulating surfaces are \( j_n = 0 \).

4. Example

A screwed joint of two steel plates is modeled as an example. The plates are 100 mm wide and 4 mm thick. The bolts and the nuts are M10. Following figures show a simulation of corrosion attack in the form of corrosion rate (mils per year). Input parameters are changed to demonstrate the influence on the corrosion. Notice the order of magnitude differences of the scales. Fig. 2 shows plates from mild steel and bolts and nuts from galvanized iron. In the model all surfaces are covered with 0.1 mm thick layer of NaCl solution (concentration 1 M, conductivity 8.60 S/m). This electrolyte was chosen because it is similar to the solution used during standard corrosion tests. Galvanized iron as a less noble material corrodes. When the surface of less noble material is relatively larger, the corrosion rate is decreased, as can be seen in the Fig. 3 (plates from galvanized iron, bolts and nuts from mild steel). Fig. 4 shows the situation from Fig. 2 but with thinner layer of electrolyte (0.01 mm). The corrosion rate is lower because of higher resistance of the electrolyte layer and the corrosion rate decreases more rapidly with the distance from the material interface. Influence of electrolyte composition can be seen in Fig. 5. Materials used are the same as in the Fig. 2 but 0.1 mm thick layer of tap water (conductivity 0.044 S/m) was used as an electrolyte. The corrosion rate is much lower and more spread along the corroding surface even with comparison with Fig. 4. This is given by higher resistance of the electrolyte layer and by the different polarization curves too. Fig. 6 shows the influence of the

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**Figure 2.** Plates – mild steel; bolts and nuts – galvanized iron; electrolyte – 1 M NaCl, the thickness of the electrolyte layer 0.1 mm

**Figure 3.** Plates – galvanized iron; bolts and nuts – mild steel; electrolyte – 1 M NaCl, the thickness of the electrolyte layer 0.1 mm

**Figure 4.** Plates – mild steel; bolts and nuts – galvanized iron; electrolyte – 1 M NaCl, the thickness of the electrolyte layer 0.01 mm
inputs and the electrolyte composition determines choice of used polarization curve.

6. Conclusions

BEASY Corrosion Manager is a programme for solving macroscopic problems. It gives information about the risk of galvanic corrosion. Assumption of the thin film electrolyte and mathematical simplification to 2D problem brings lower computational demands. The programme does not solve details of the electrochemical processes. This brings a necessity of large polarization curves database. The main issue during application of the programme is determination of the thin film electrolyte parameters. Even though the determination of input data is exacting process the results of analysis are important for good understanding of corrosion processes. Software analysis can be a useful tool for the materials engineering.

References


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Figure 5. Plates – mild steel; bolts and nuts – galvanized iron; electrolyte – tap water, the thickness of the electrolyte layer 0.1mm

Figure 6. Plates – mild steel; bolts and nuts – stainless steel; electrolyte – 1M NaCl, the thickness of the electrolyte layer 0.1mm

materials. The plates are from mild steel and the bolts and the nuts are from stainless steel (304 grade). Electrolyte is 0.1 mm thick layer of NaCl solution. Here the less noble material is mild steel, it has larger surface than the more noble material (stainless steel) and the corrosion rate is the lowest.

5. Discussion

Analysis of corrosion resistance using the corrosion manager consider homogenous layer of electrolyte. Used mathematical model solves the electrical neutrality of the electrolyte layer. Assumption of thin layer allows further simplification and solving the 2D problem. This assumption means that the electrical potential can be considered constant along the thickness of the layer. Here, the thickness of the layer enters into the mathematical treatment of the problem.

BEASY Corrosion Manager does not solve processes during the polarization such as diffusion, migration or chemical reactions. For a given material, the parameters influencing the polarization process are composition of the electrolyte, composition of the atmosphere, which is especially important in the case of the thin layer, and thickness of the layer. Here, the thickness of the layer influences the shape of the polarization curve [Morris 1989, Thébault 2011, Xiao 2012].

Polarization curves have to consider the influence of temperature, which is crucial for the kinetics and influences conductivity of the electrolyte as well. Influence of all these phenomena has to be contained in the polarization curves.

For application of the programme it is necessary to have a large database of polarization curves. Measurement in the thin film of electrolyte is fairly difficult [Stratmann 1990, Liao 2011, Xiao 2012]. Another problem during the application of described program is to determine the properties of the film regarding thickness, conductivity and composition. The thickness and the conductivity are direct