

Modeling of Galvanic Interactions Between AA5083 and Steel Under Atmospheric Condition

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Background



<http://www.globalsecurity.org/military/systems/ship/lcs-design.htm>

AA5083 alloys are widely used across the Department of Defense

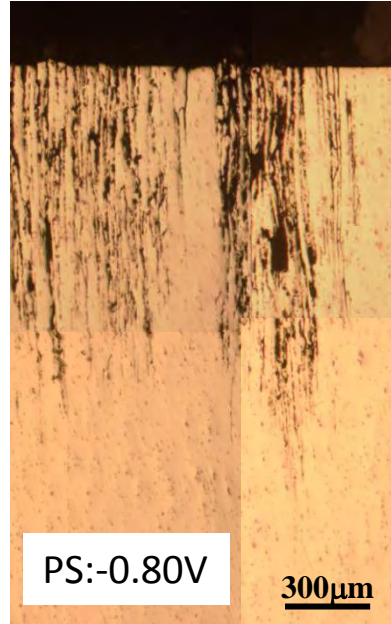
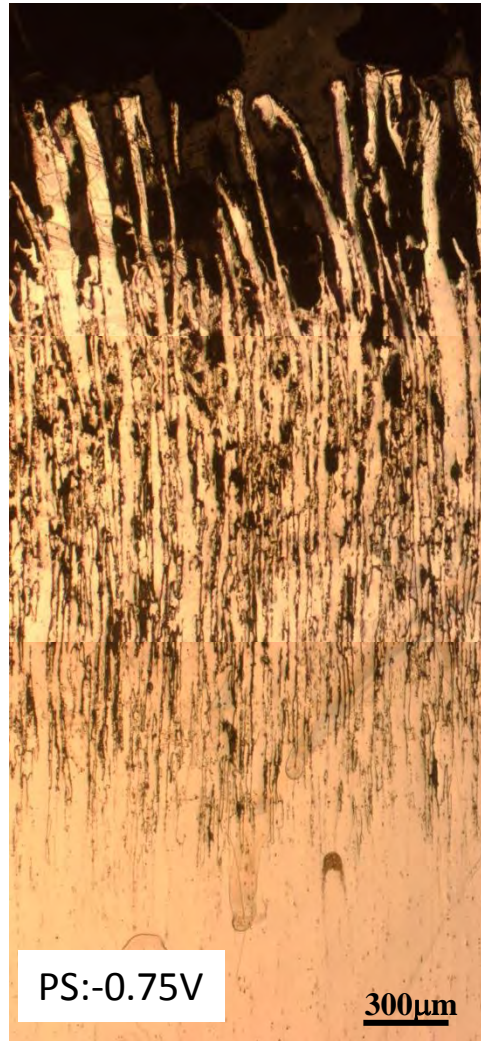
- AA5083 is susceptible to IGC and IGSCC due to the sensitization during service
- Aluminum alloys are often joined via steel bolts



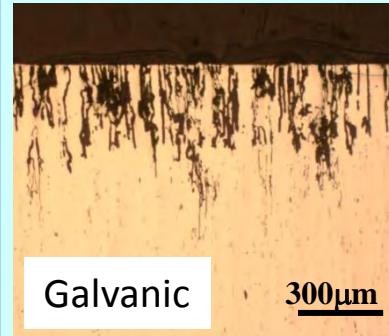
There is a concern that galvanic interactions will exacerbate corrosion of the AA5083 leading to IGC and IGSCC.

IGC damage of AA5083

Potentiostatic test

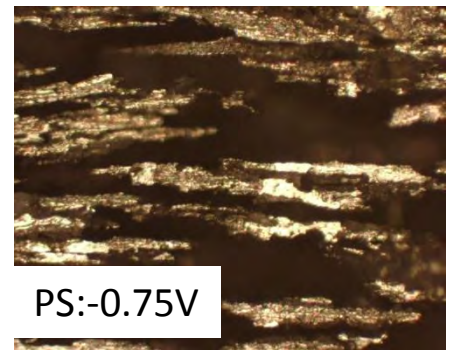
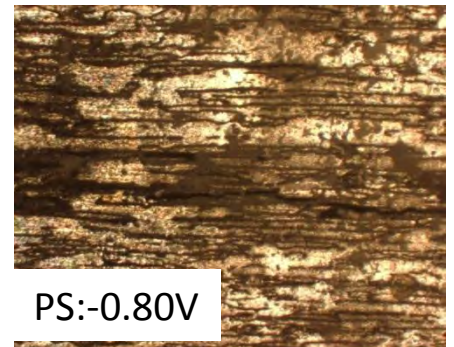
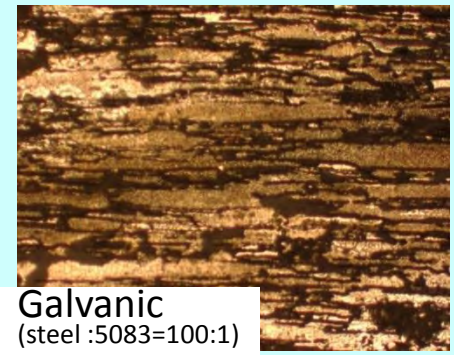


Galvanic corrosion
(steel :5083=100:1)



Avg potential = -0.85 V

Solution : 0.6MNaCl
Test duration : 100hours



200µm

Galvanic corrosion under atmospheric condition is complicated due to the range of factors affecting the corrosion.

Example : salt loading density, relative humidity, area ratio, temperature, geometry ...

It is necessary to investigate the influence of each environmental factor systematically to understand galvanic atmospheric corrosion.

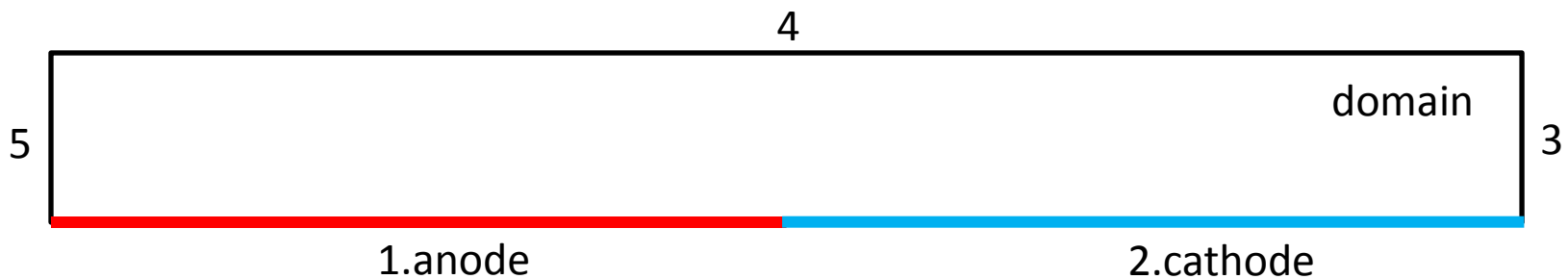
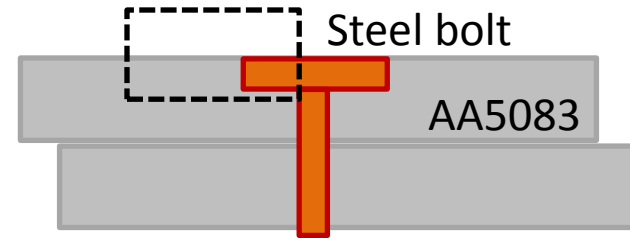


It is impossible to investigate so many conditions experimentally in the laboratory.

Objective

To build the preliminary model to predict the potential and the current density distribution due to the galvanic coupling between AA5083 aluminum alloy and AISI4340 steel under a thin electrolyte to simulate atmospheric corrosion.

Model geometry



Nernst-Planck equation:

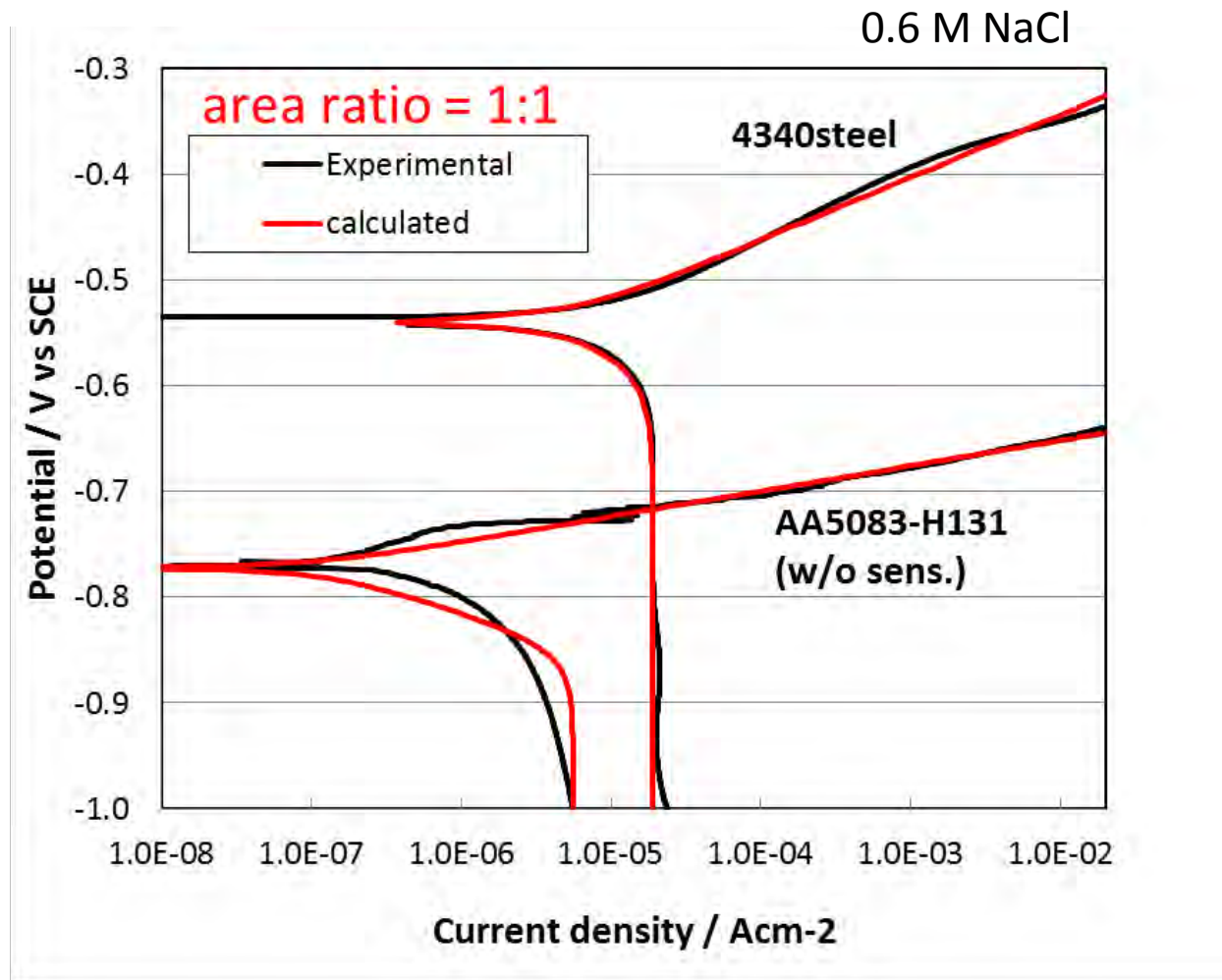
$$\frac{\partial c_i}{\partial t} = \nabla \cdot \left(-D_i \nabla c_i - z_i F \frac{D_i}{RT} \nabla \phi \right) = R_i \quad (1)$$

$$\sum z_i c_i = 0$$

Parameters for chemical species

	Initial Concentration (mol·m ⁻³)	Diffusion Coefficient (m ² ·s ⁻¹)
Na ⁺	600	1.3 x 10 ⁻⁹
Cl ⁻	600	2.0 x 10 ⁻⁹
H ⁺	10 ⁻⁴	9.3 x 10 ⁻⁹
OH ⁻	10 ⁻⁴	5.3 x 10 ⁻⁹
Al ³⁺	0	10 ⁻⁹

Determination of Boundary Conditions



Boundary conditions

Equation consists of Butler-Volmer equation and cathodic diffusion plateau

Boundary-1 : Anodic reaction (on AA5083)

$$i_{AlO} \cdot \exp(-\alpha_{Ala} \cdot (E_{AlO} - (V_m - V))/R/T) + i_{AlLim} \cdot i_{AlO} \cdot \exp(\alpha_{Alc} \cdot F \cdot (E_{AlO} - (V_m - V))/R/T) / (i_{AlLim} + i_{AlO} \cdot \exp(\alpha_{Alc} \cdot F \cdot (E_{AlO} - (V_m - V))/R/T))$$

Boundary-2 : Cathodic reaction (on steel)

$$i_{FeLim} \cdot i_{Fe0} \cdot \exp((\alpha_{Fec} \cdot F \cdot (E_{Fe0} - (V_m - V))/R/T) / (i_{FeLim} + i_{Fe0} \cdot \exp(\alpha_{Fec} \cdot F \cdot (E_{Fe0} - (V_m - V))/R/T))$$

Boundary	type	Parameters				
1	anode	$i_{AlO} (A/m^2)$	$E_{AlO} (V_{SCE})$	$i_{AlLim} (A/m^2)$	α_{Ala}	a_{Alc}
		9.6×10^{-4}	-0.772	-5.6×10^{-2}	2.5	1.5
2	cathode	$i_{Fe0} (A/m^2)$	$E_{Fe0} (V_{SCE})$	$i_{FeLim} (A/m^2)$	α_{Fea}	
		-5.6×10^{-2}	-0.535	-1.9×10^{-1}	1.0	

Other conditions

The limiting current density by oxygen diffusion

$$i_{\text{FeLim}} = zFD_{\text{O}_2}C_{\text{O}_2} / d \quad d:\text{thickness of diffusion layer}$$

The flux due to the electrochemical reaction

Boundary	Type	Reaction	flux of species
1	anodic reaction	$\text{Al} \rightarrow \text{Al}^{3+} + 3\text{e}^-$	$j_{\text{Al}^{3+}} = i_a / 3F$
2	cathodic reaction	$\text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^- \rightarrow 4\text{OH}^-$	$j_{\text{OH}^-} = i_c / F$
3-5	electric insulator	—	—

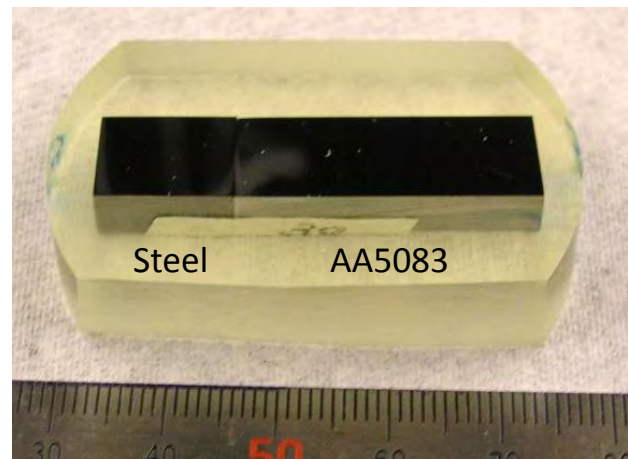
The chemical reaction in domain:



$$R_{\text{H}^+} = R_{\text{OH}^-} = k_{\text{wf}} - k_{\text{wb}} \cdot [\text{H}^+] - [\text{OH}^-]$$

$$\text{where } k_{\text{wf}} = 10^{-4} \text{ and } k_{\text{wb}} = 10^4$$

Scanning Kelvin Probe (SKP)



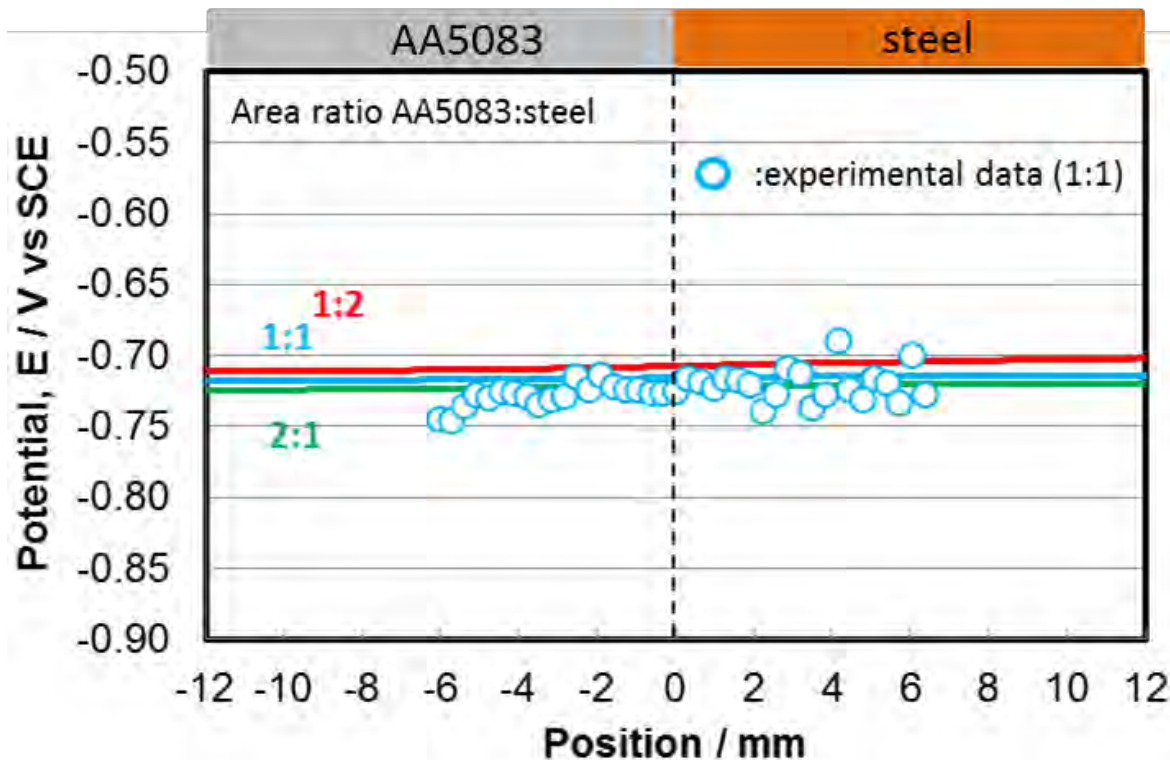
AA5083-H131 and steel were combined together in epoxy resin (low sensitized 5083 was used)

0.6M NaCl was used to form the thin electrolyte layer

Thickness of electrolyte : 1.0 and 0.1 mm

RH was set at 98% to keep the condition of electrolyte.

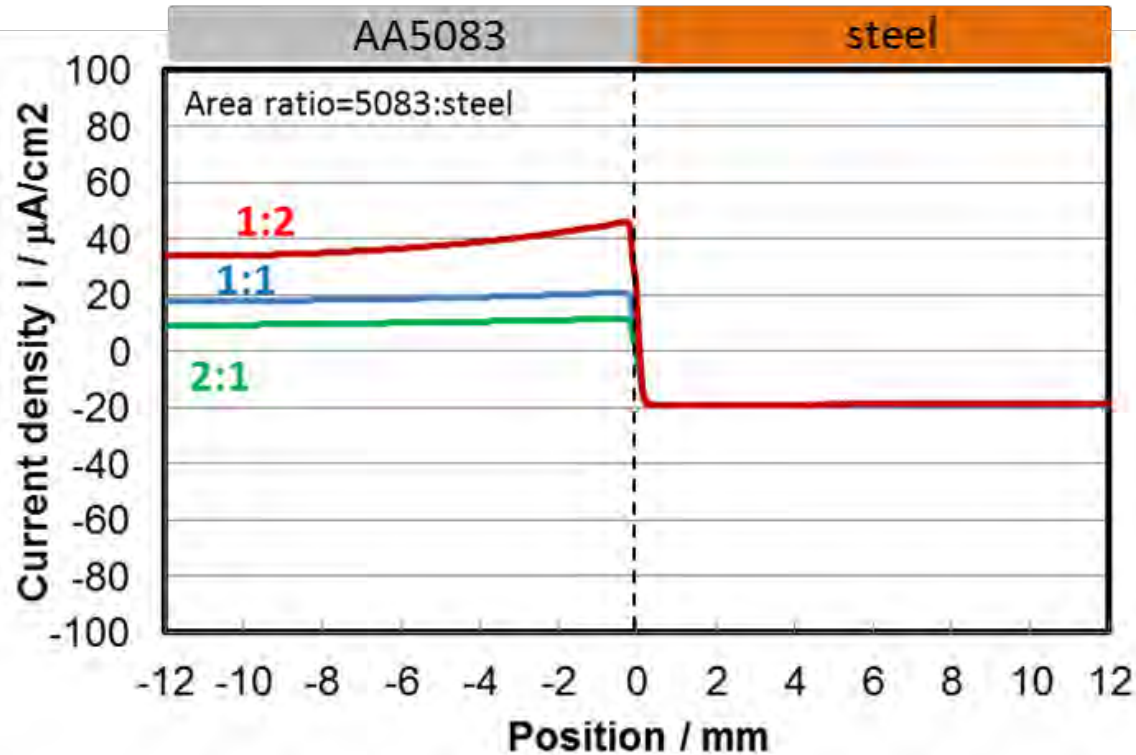
Potential distribution under 1.0mm film



- Potential calculated by model had a good agreement with experimental data.

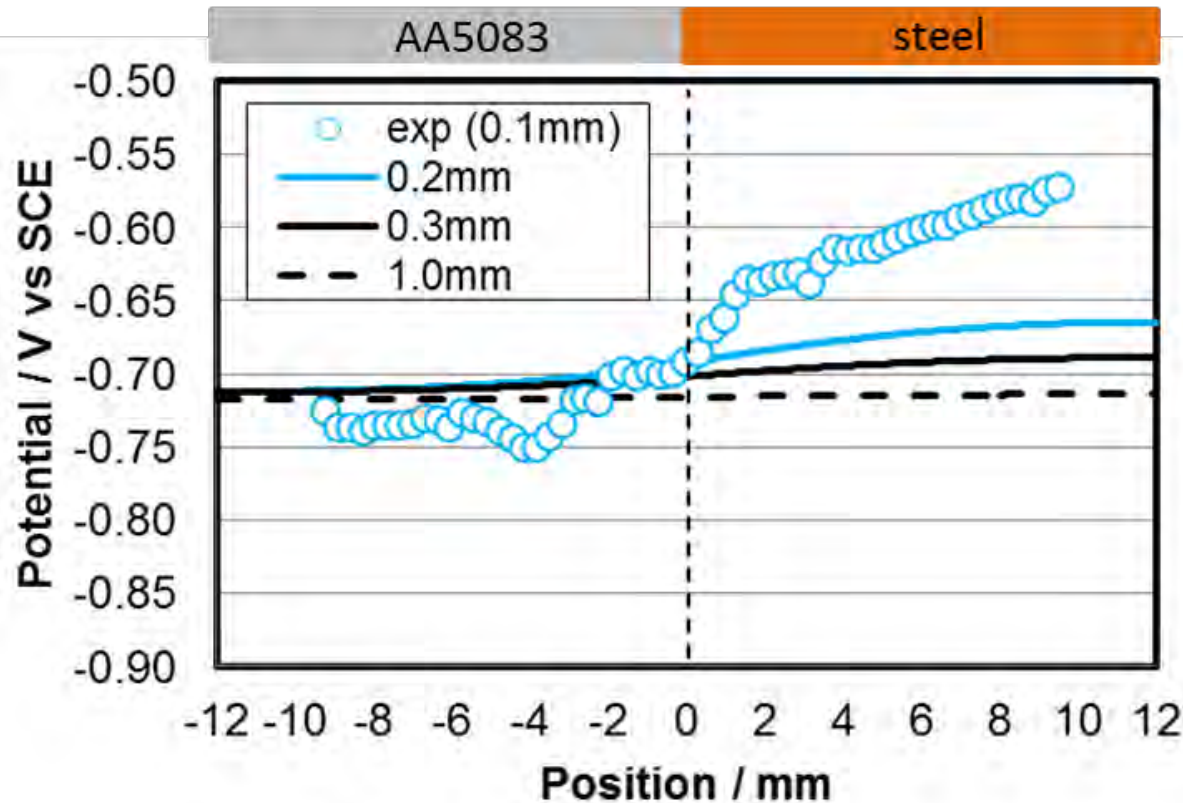


Current density distribution under 1.0mm film



- Anodic current density on the 5083 increased with increasing the area ratio of steel.
- Anodic current density was almost constant in each area ratio condition.

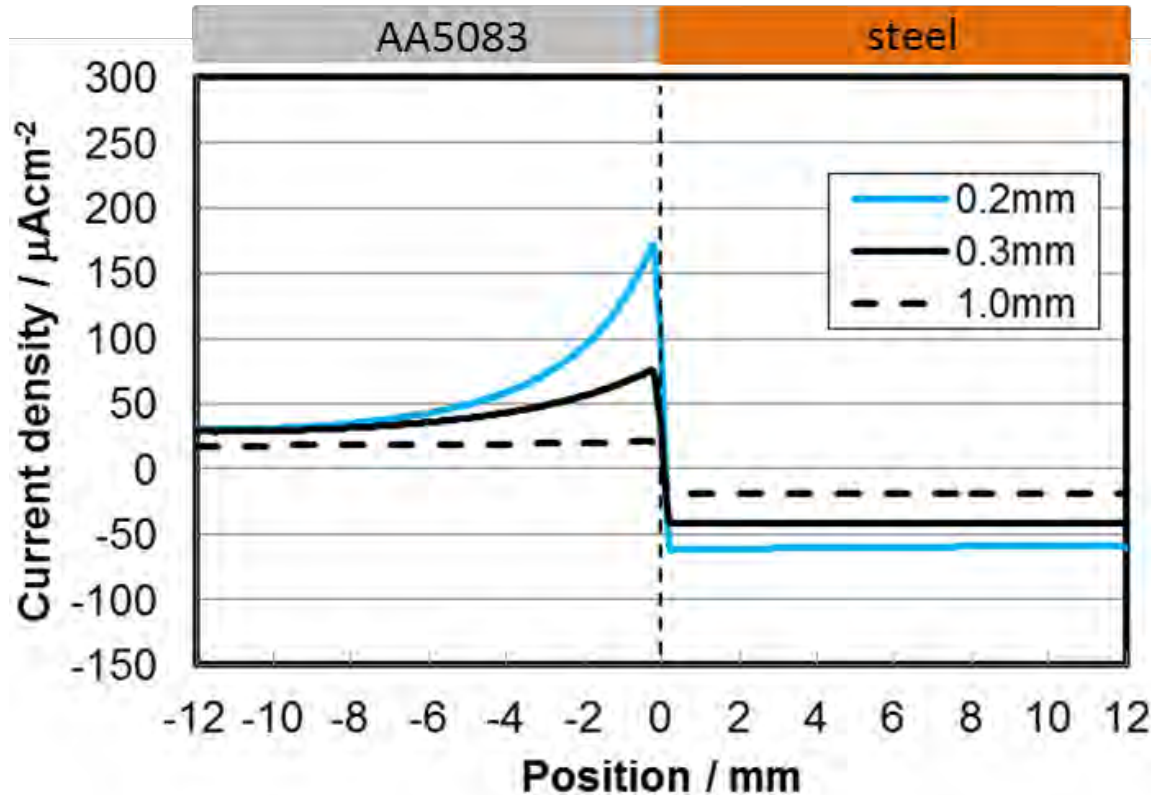
Potential distribution under thin film



- The tendency of potential was similar between model calculation and experimental data.



Current density distribution under thin film



- Galvanic interaction under atmospheric condition will exacerbate the corrosion of AA5083 near its boundary with steel.

Summary

1. The preliminary model for predicting galvanic corrosion under atmospheric condition was developed.
2. Potential distribution in bulk solution calculated from this model had a good agreement with experimental data.
3. Potential distribution under thin electrolyte calculated from this model had similar tendency to the experimental data.
4. The model calculation indicates that galvanic interaction would exacerbate the corrosion of 5083 under atmospheric condition, with thinner electrolytes focusing the attack near the boundary with the steel.

Future work

1. To improve the model so that we can calculate under thinner electrolyte (less than 0.1mm).
2. To compare the IGC damage distribution predicted from the model with experimental data.

Thank you for your attention








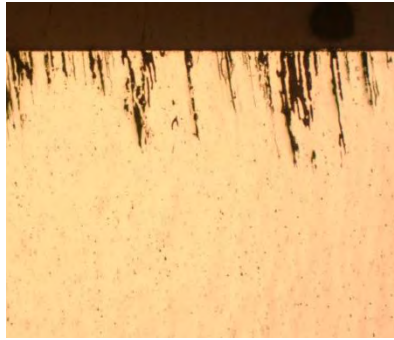

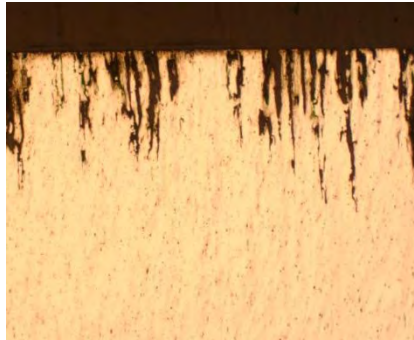
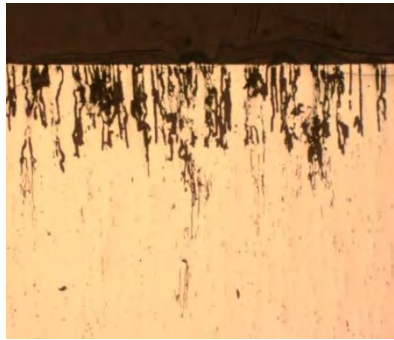
Appendix

Corroded surface observation

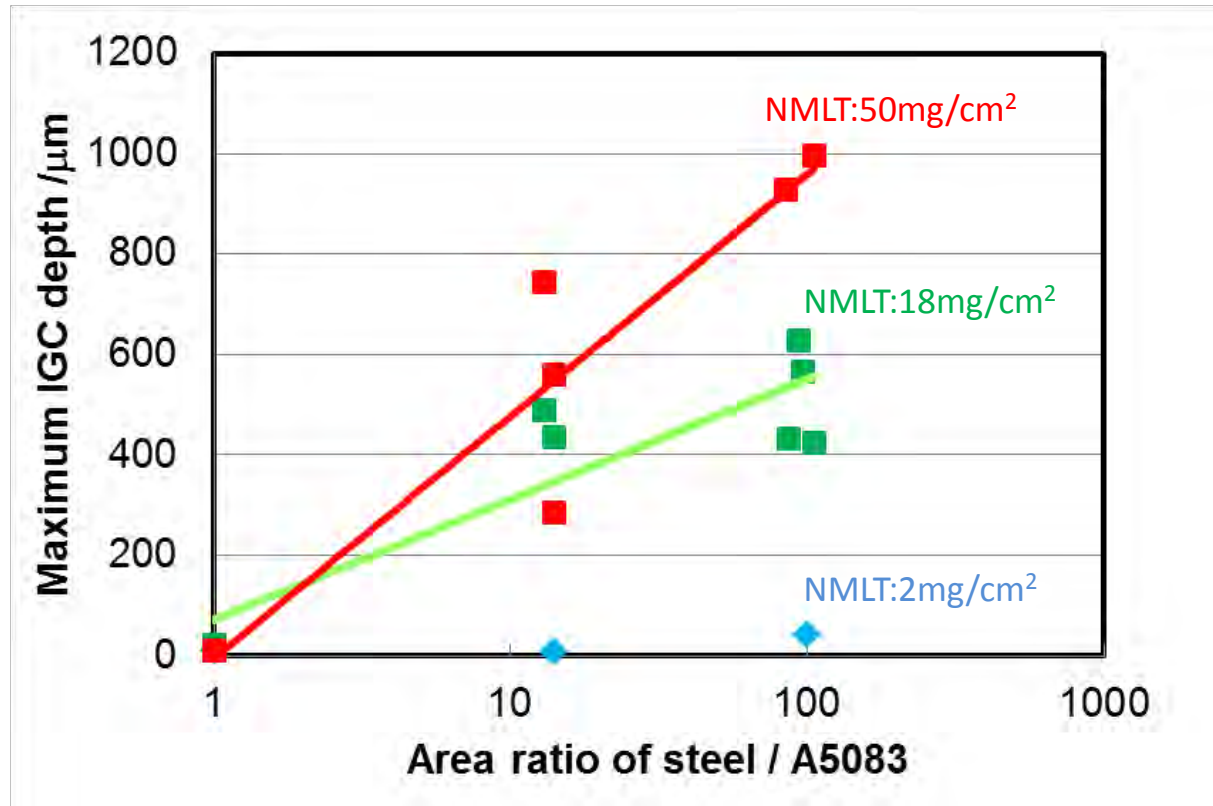
Area ratio	DoS 2mg/cm ²	DoS 18mg/cm ²	DoS 50mg/cm ²
1:1 √ → T S			
1:15			
1:100			

200μm

IGC damage by galvanic interaction

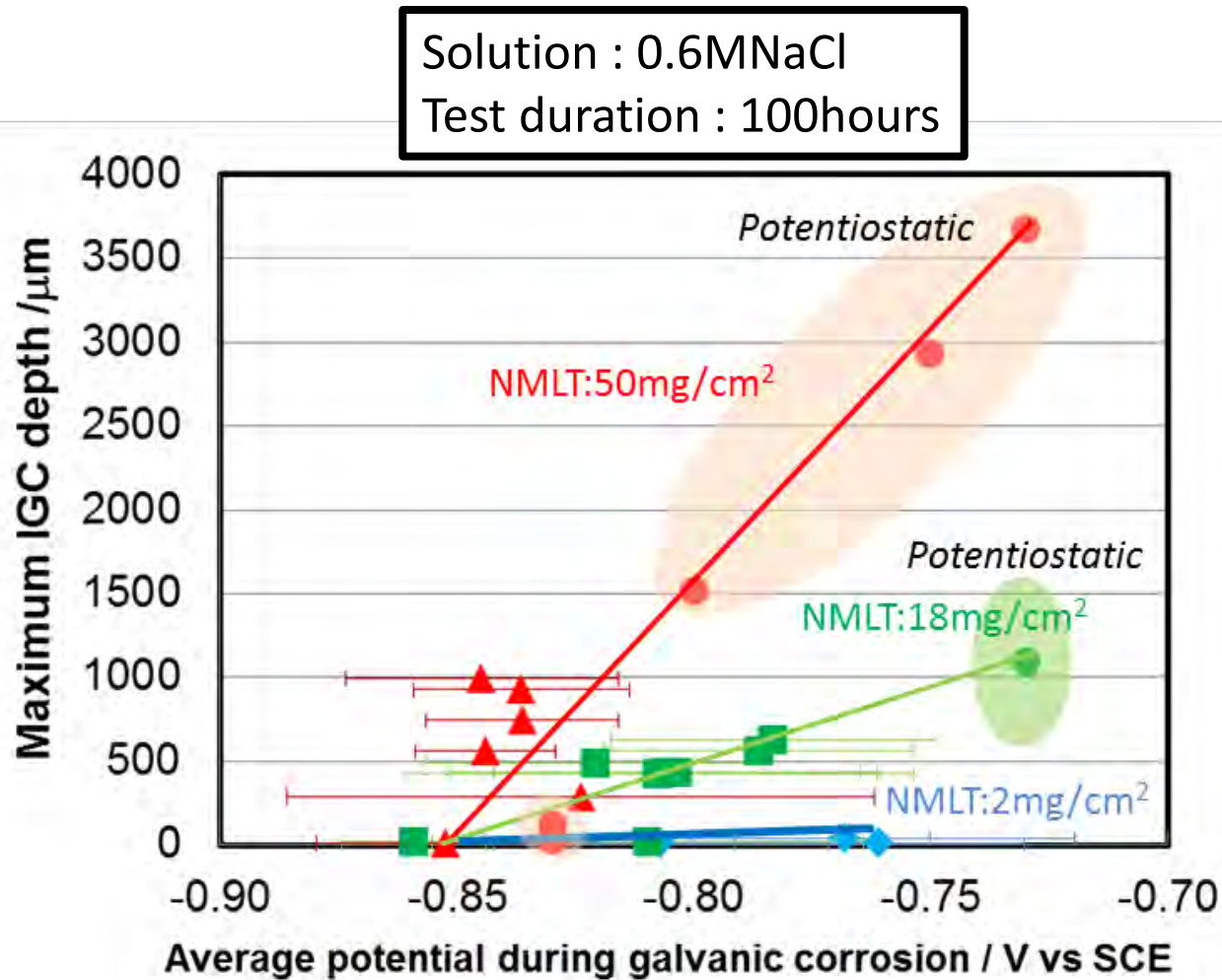
Area ratio	DoS 2mg/cm ²	DoS 18mg/cm ²	DoS 50mg/cm ²
1:1 ↙ ↘ S L			
1:15			
1:100			

Influence of area ratio on IGC



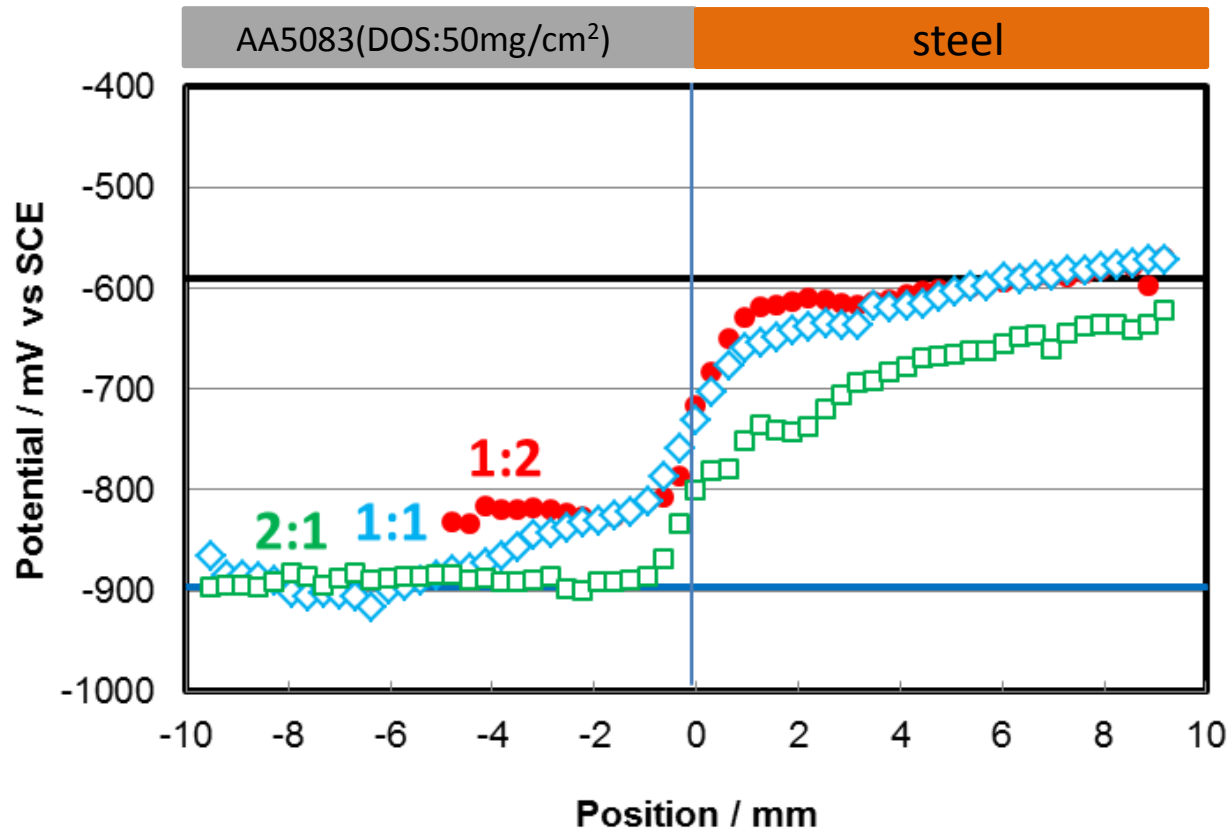
- IGC depth tends to be deeper with increasing area ratio of steel.
- Dependence of area ratio on IGC increased with increasing DoS.
- IGC attack seems to have the power law relationship with area ratio.

The relationship between IGC damage and potential



Potential distribution under thin electrolyte

Under 0.1mm thick 0.6M NaCl



- Potential on 5083 near its boundary with steel was polarized to positive value which can cause IGC.

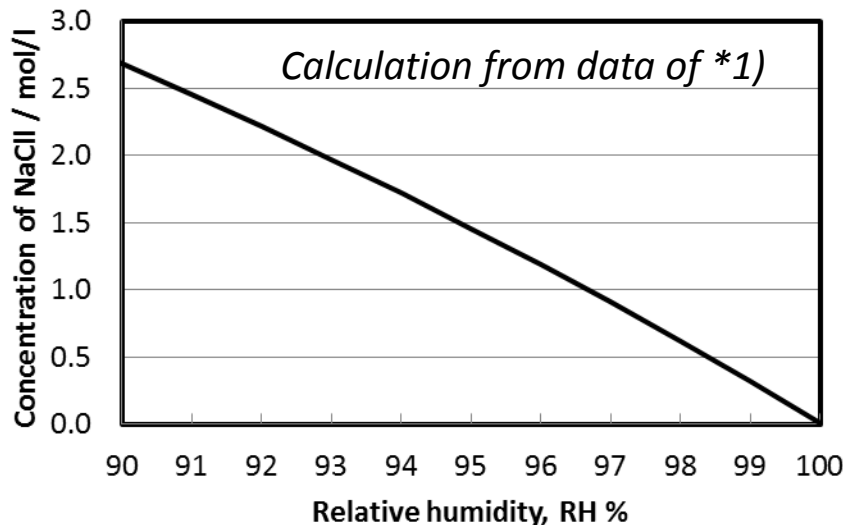
Why 0.6M-NaCl ?

- Considering the situation that AA5083 alloys were used on the cabin of ships, they can get splash of sea water.

0.6M NaCl splash



Concentration of NaCl increases with decreased thickness of electrolyte due to dry up

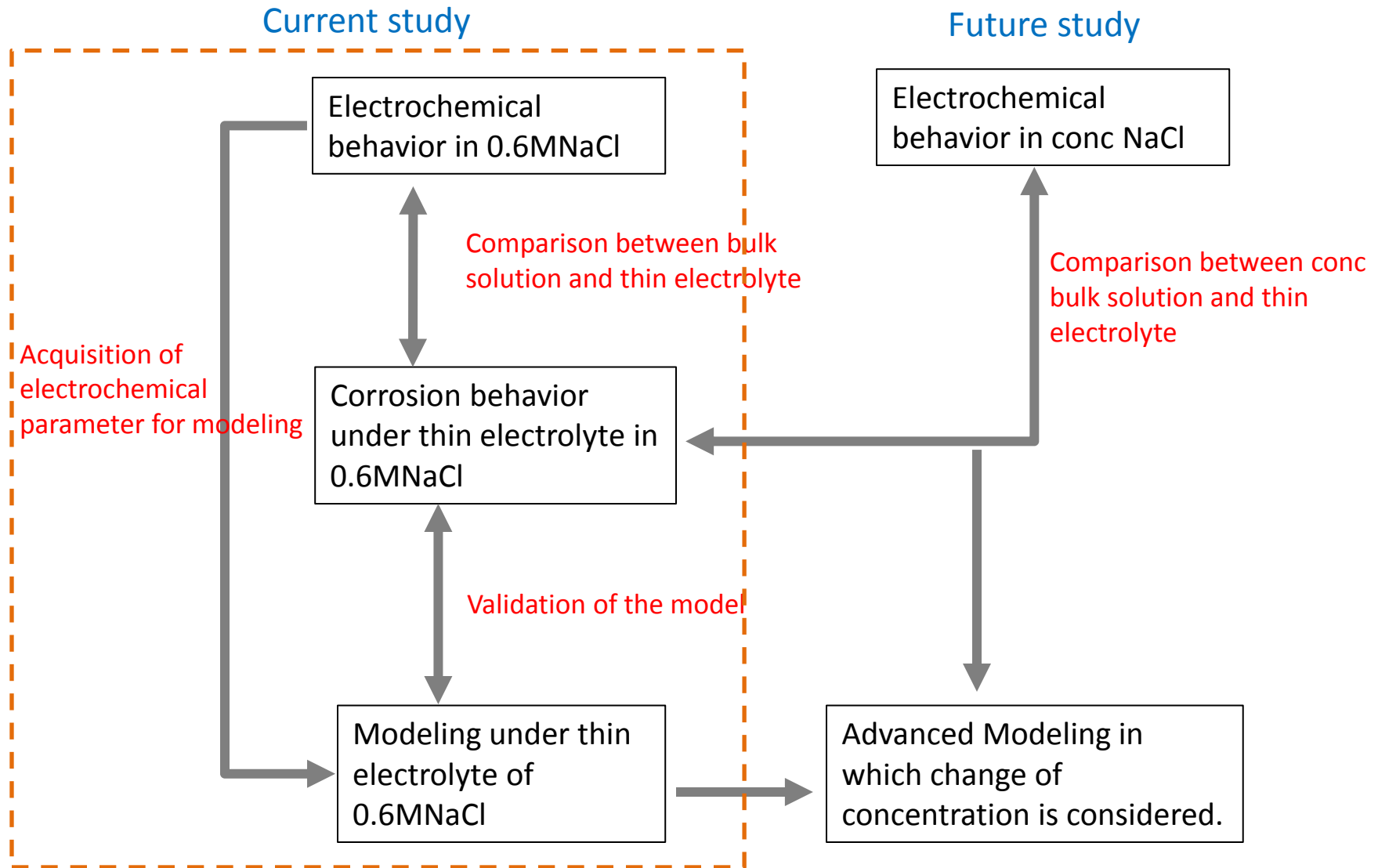


The equivalent concentration changes depending on RH

*1): J. C. W Frazier et al, International Critical Tables of Numerical Data, Physics, Chemistry and Technology Vol. III, W. W. Washburn, Editor, p292, McGraw-Hill, New York (1928).

It is difficult to add the influence of the thin electrolyte and the change of concentration due to the evaporation of water at the same time.

Why 0.6M-NaCl ?



We focused on developing the model which we can apply under thin electrolyte first. In order to validate it, 0.6M NaCl should be used.

Problem of current model

The thickness of electrolyte is thick, calculation will converge.

However, the thickness of electrolyte is less than 0.1mm, calculation will NOT converge.



Thin electrolyte

AA5083

Steel



Thin electrolyte

AA5083

Steel

The problem is ...

How to make the mesh ?

Aspect ratio ?

Boundary condition ?