A Model to Simulate Cathodic Protection of Steel by Thermally Sprayed Aluminium in Presence of Defect

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Motivation

Thermal spray aluminium (TSA) coatings have been reported to provide cathodic protection of steel structures under immersed conditions in marine environments. However, the level of damage these coatings can tolerate is not fully explored. Simulations using COMSOL Multiphysics ®, were conducted to understand the behaviour of sacrificial aluminium coatings obtained by arc spray with varying areas of damage and its capacity to polarise steel in artificial seawater.

Model System

• Reactions

When TSA - coated steel with defect is exposed to seawater, the oxygen reduction reaction happens on steel surface, while anodic reaction happens on the coating[1].

$$O_2(g) + 2H_2O(l) + 4e^- \quad 4OH^-(aq)$$

$$Al(s) \quad Al^{3+}(aq) + 3e^-$$

• Geometry

Experiment A. Electrochemical behaviour of AA 1050 coating with damage in artificial seawater[2].

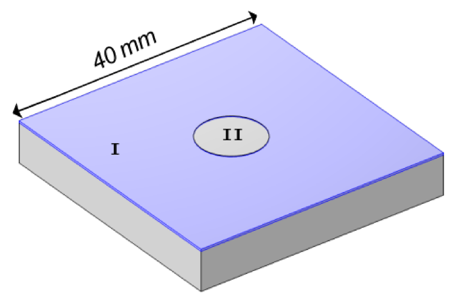

Figure 1: Thermally sprayed coated sample with 5 % of surface area defect. (I) TSA coating. (II) Steel exposed.

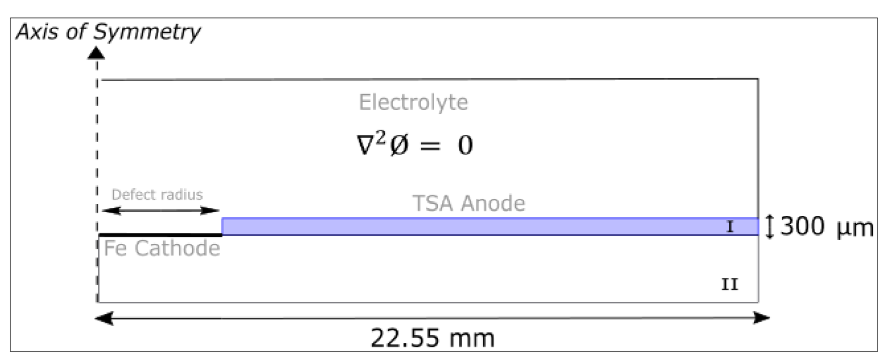

Figure 2: Geometry of the model. 2D axi-symmetric space dimension.

Experiment B. Testing of AA 1050 coating in artificial seawater with extreme damage[3].

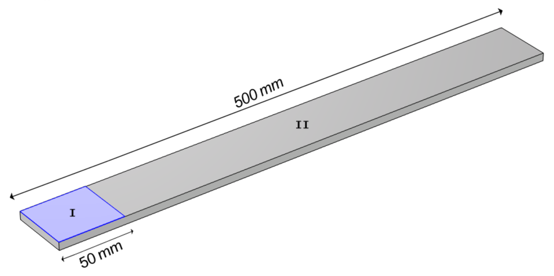

Figure 3: Thermally sprayed coated sample with 90 % of surface area defect. (I) TSA coating. (II) Steel exposed.

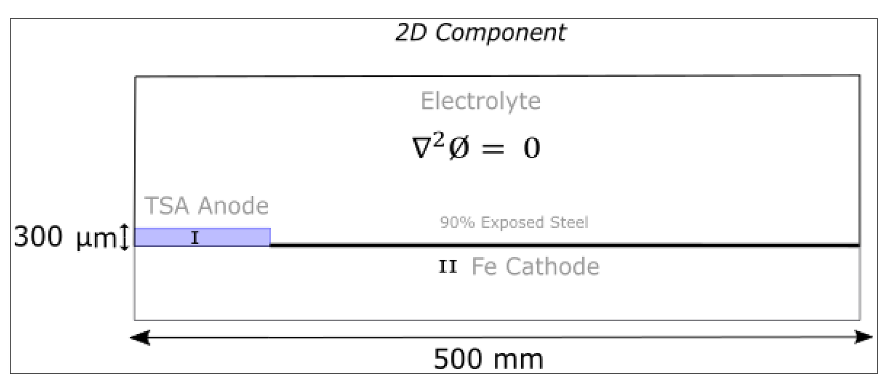

Figure 4: Geometry of the model. 2D space dimension.

Boundary Conditions

• Governing Equations

Transport of species is represented by Nernst-Planck equation

$$N_i = -D_i \quad c_i - z_i F u_i c_i \quad \varphi + c_i v \tag{1}$$

Steady-state electrolyte, the solution velocity v is zero

$$\frac{\partial c_i}{\partial t} = - \quad . N_i = 0 \tag{2}$$

Electrolyte is assumed electroneutral

$$\sum_i^n z_i c_i = 0 \tag{3}$$

The cathode is assumed to be not corroding

$$^2\varphi = 0 \tag{4}$$

Ohm's law is applied to calculate potential gradient on the anode boundarie

$$\varphi = -\frac{j_a}{\sigma} \tag{5}$$

where j_a is the local current density and σ is the electrolyte conductivity[4].

Parameters

Parameter	Value	Source
E_{corr} Steel	-0.68 V	[3]
E_{corr} AA1050	-0.98 V	[1, 2]
$jcorr$	$5.5x10^{-2} \frac{A}{m^2}$	[1]
α_a	0.57 V/dec	[1]
α_c	0.18 V/dec	[1]
σ	5 S/m	

Table 1: Mixed potentials are referred to Ag/AgCl (Sat.KCl) electrode.

• Time - Dependent Modelling

Arbitrary Lagrangian Eulerian (ALE) was used as a moving mesh technique to simulate the consumption of the TSA coating surface[4]. Corrosion products and deposit layers are not taken into account in the model.

$$n.v = \frac{M j_{corr}}{zF\rho} = \frac{M j_a}{zF\rho} \tag{6}$$

Results

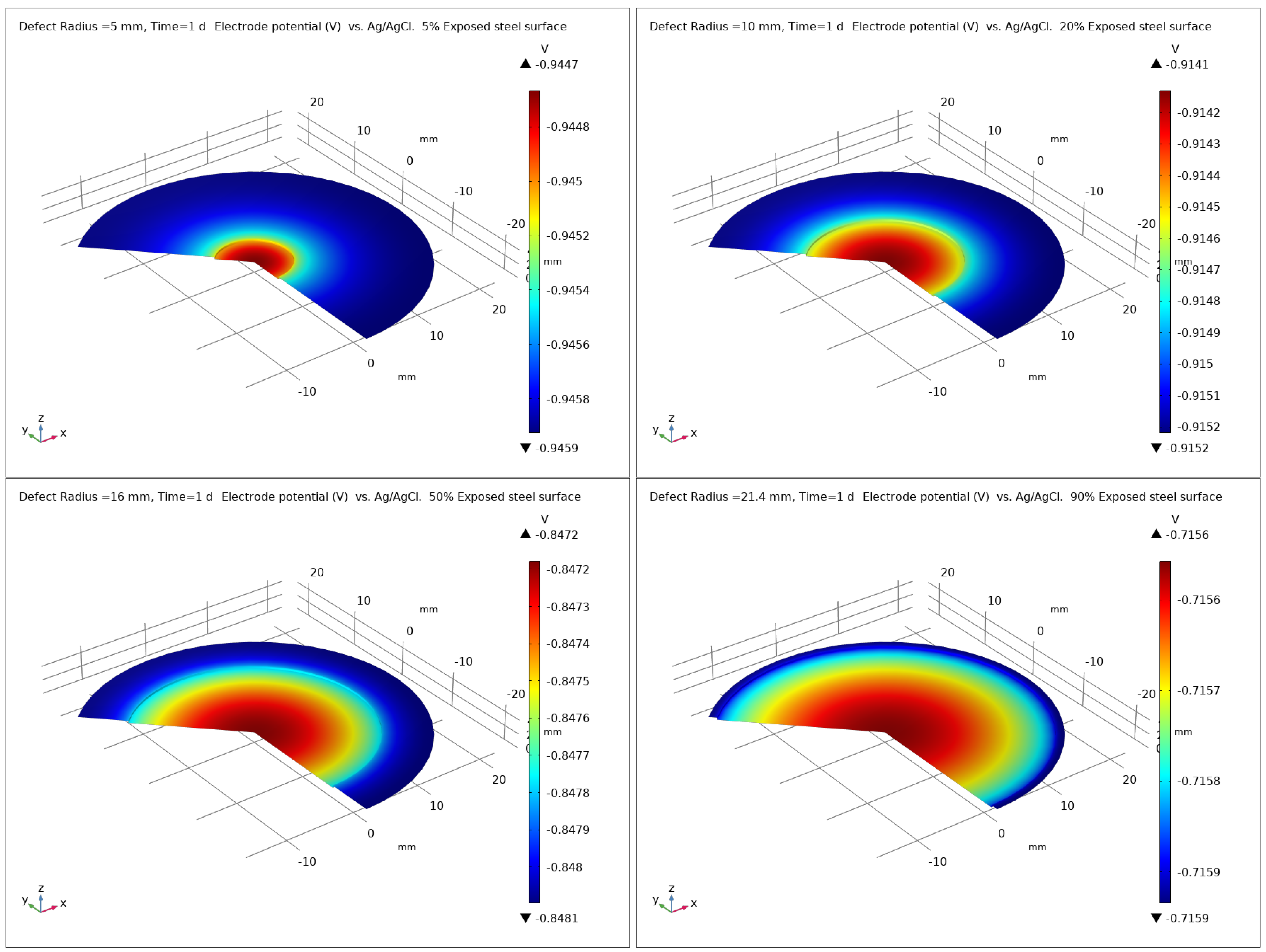

Figure 5: Sacrificial protection offered by thermal spray aluminium coating as a function of the exposed steel surface area.

Comparison With Experiments

Experiment A. Open circuit potential (OCP) within 50 days.

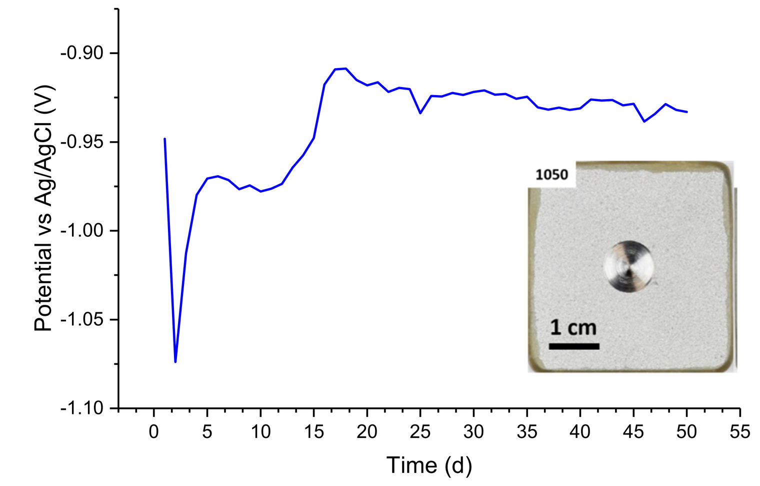

Figure 6: OCP of thermally sprayed coated sample with 5 % of surface area defect[1, 2].

Experiment B. $C_{R,Exp} = 0.42\frac{mm}{y}$ [3] and $C_{R,Model} = 0.38\frac{mm}{y}$ within 7 days.

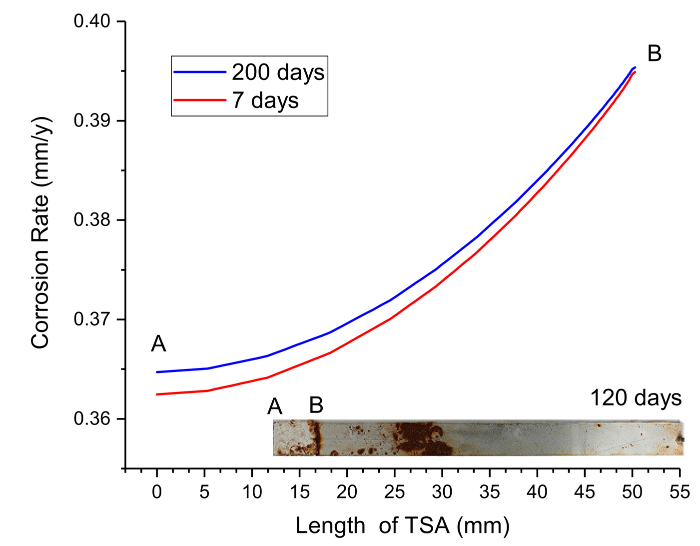

Figure 7: Simulated corrosion rates (C_R).

Conclusion and Future Work

The corrosion rates and sacrificial protection obtained using the model are in broad agreement with those estimated from laboratory experiments. Future time-dependent simulations need to integrate corrosion products and deposit layers.

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ALE Animation

Poster

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