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GALVANIC CORROSION IN BOLTED JOINTS

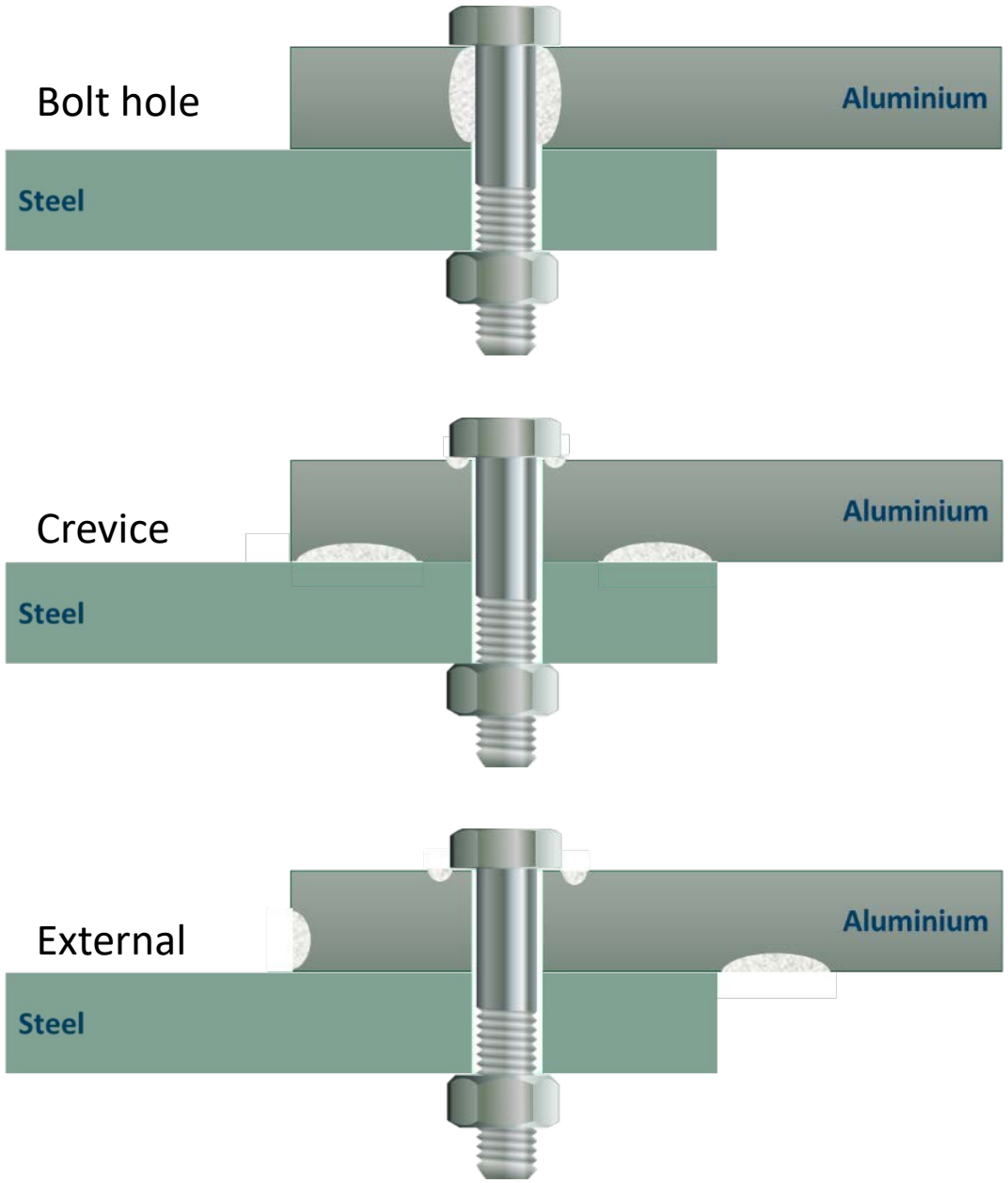
Ole Øystein Knudsen, SINTEF
Daniel Höche, Hereon

Contents

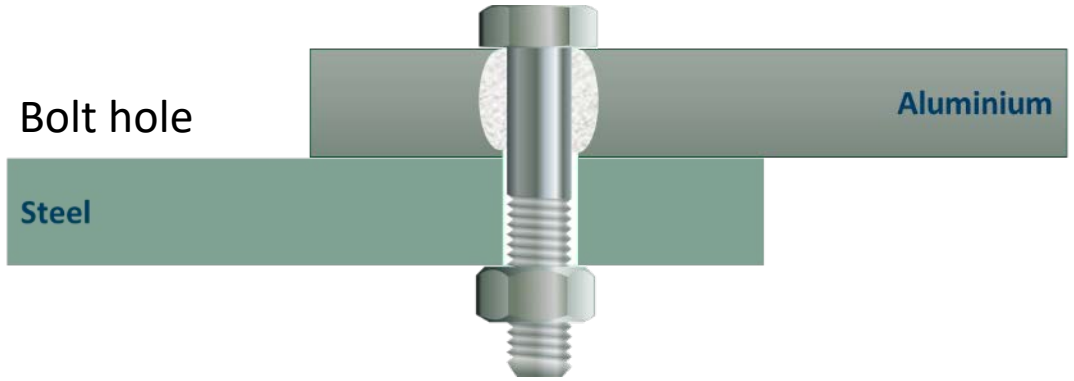
- Galvanic corrosion in bolted joints
- Potential solutions to the problem(s)
- Testing of different washer materials
- Modelling galvanic corrosion

Locus of attack

- Somewhat different corrosion attacks in the three cases
- Prevention may be different



Bolt hole

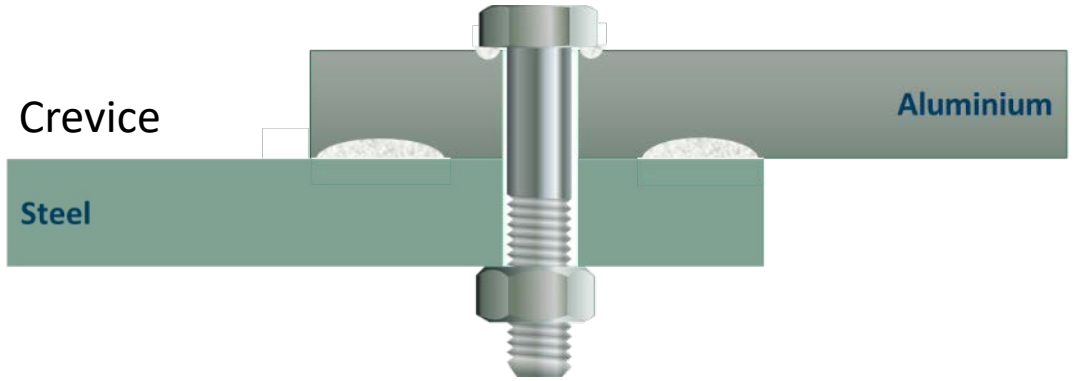


Not investigated in the project

Potential solutions

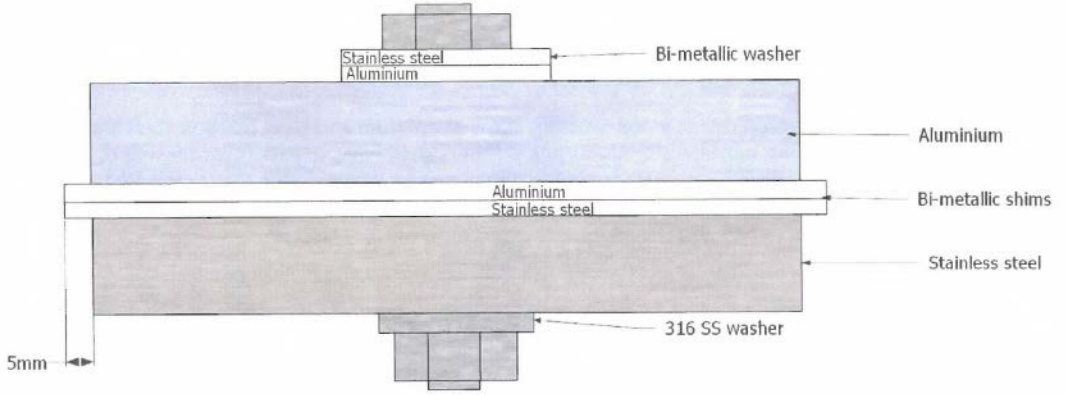
- Electrical insulation
- Prevent ingress of water in the bolthole
  - Seal the openings
  - Fill the bolthole with a sealant
- Coat the bolt
  - Sleeves or pre-coated bolts

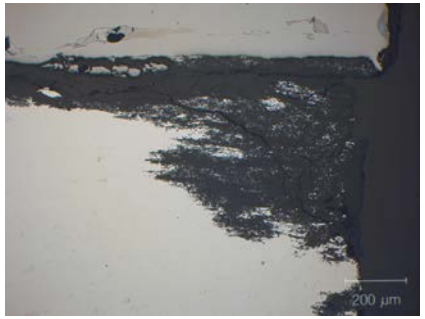
Crevice



Potential solutions

- Electrically insulating Al from steel
- Bimetallic shims
  - The Al-SS crevice is eliminated by metallurgical bonding
- Fill the crevice with a polymeric sealant
- Aluminium shims and washers that can be replaced when corroded

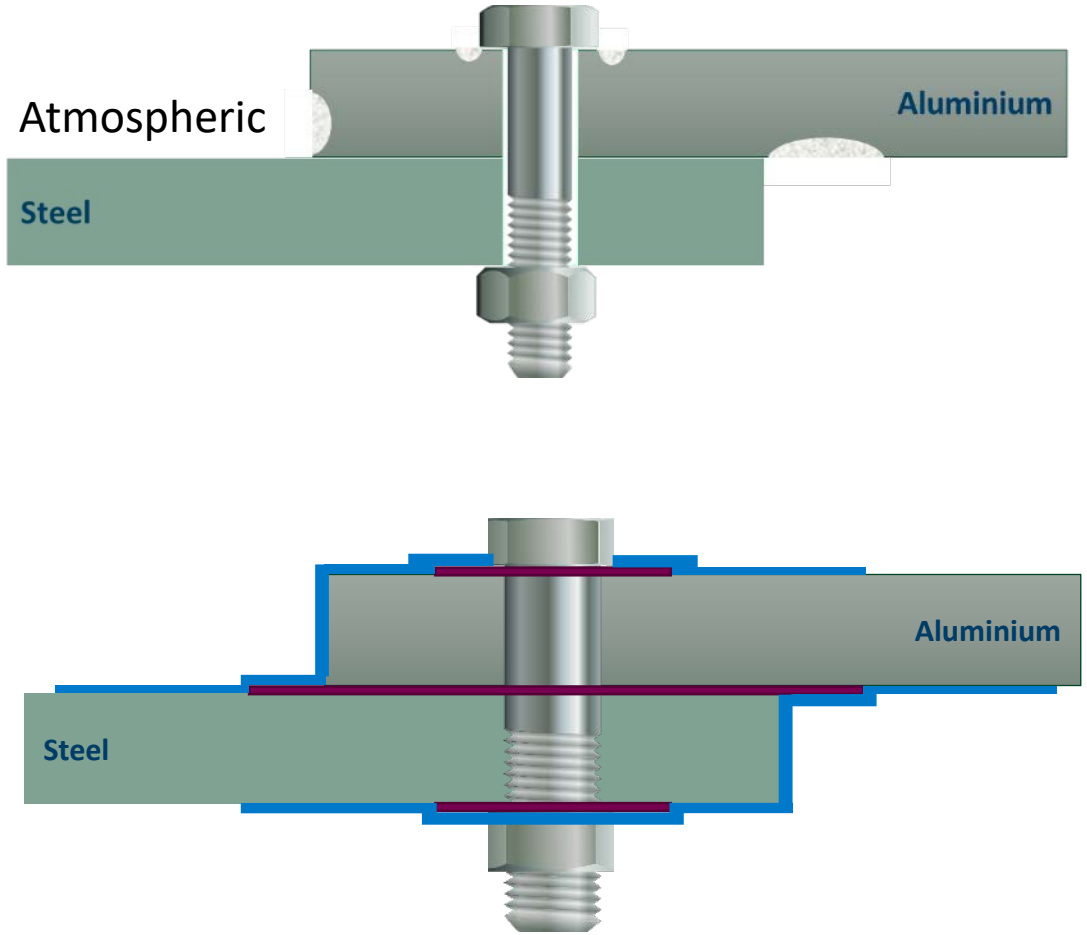




External

Potential solutions

- Electrically insulating Al from steel
- Electrolytically insulating Al from steel
- Aluminium shims and washers that can be replaced when corroded



Atmospheric corrosion test - modified ISO 11997-1*

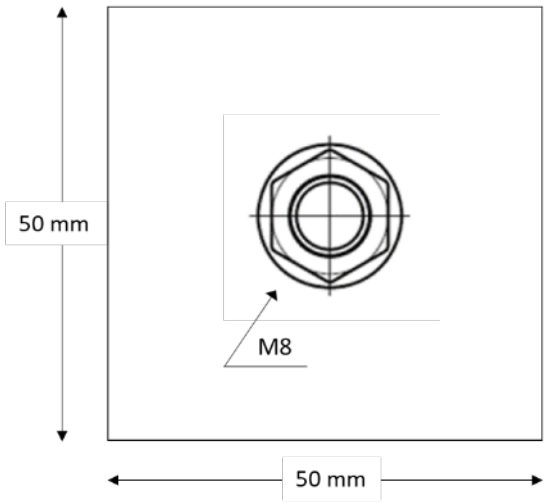


Table A.1 — Test parameters for cycle A

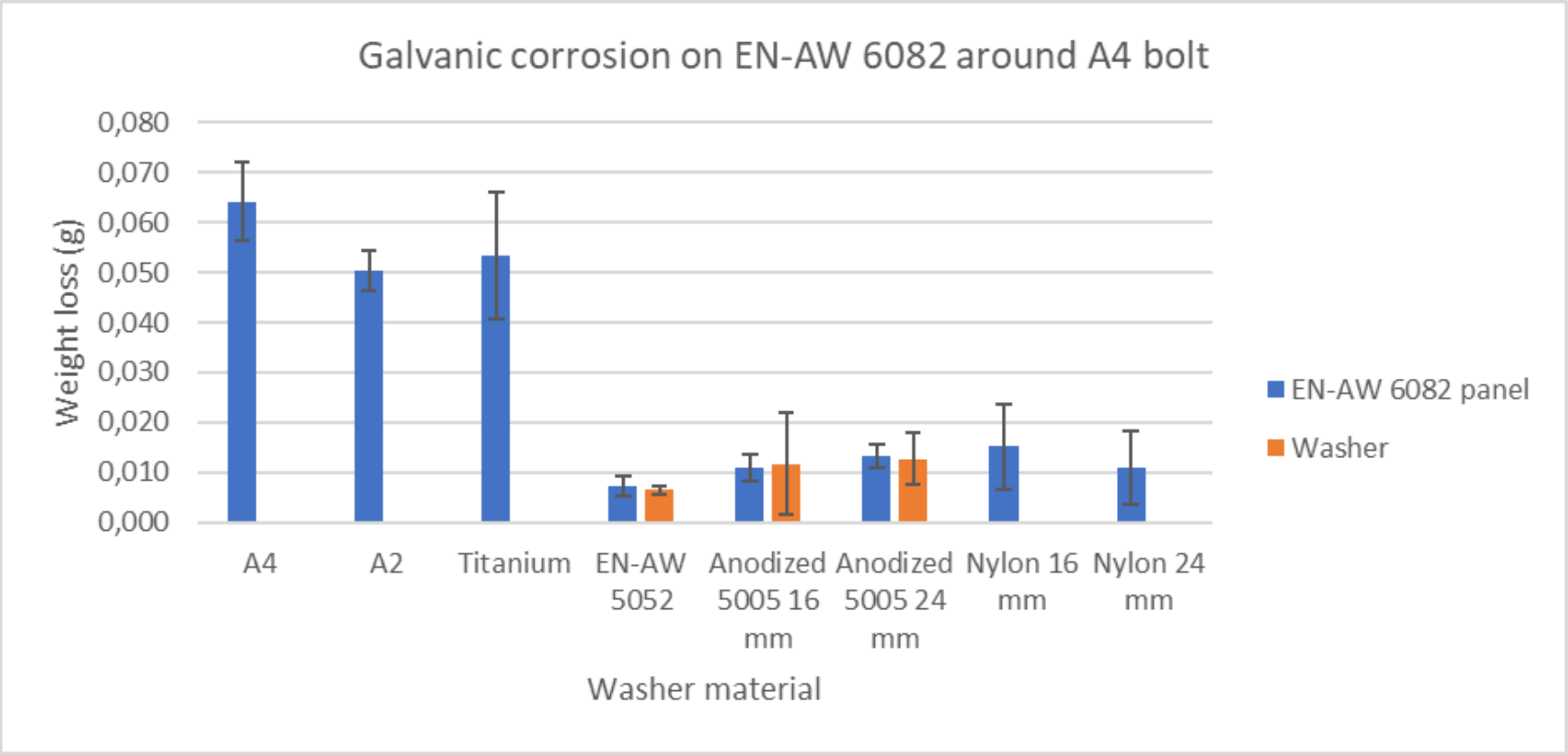
Step	Time h	Temperature °C	Condition	Notes
1	2	35 ± 2	Salt spray	—
2	4	60 ± 2	Dry: 20 % to 30 % RH	—
3	2	50 ± 2	Wet: 95 % RH or over	—
4	Go back to step 1.			This makes a total cycle time of 8 h from step 1 to step 3.
	Transition time (i.e. time allowed to reach the temperature and relative humidity specified for a condition after changing to that condition):			From salt spray to dry: within 30 min From dry to wet: within 15 min From wet to salt spray: within 30 min The effect of the salt spray will, in principle, be instantaneous. For details of drying-air flow, see 6.4.

* Artificial seawater is used as spray solution instead of 5 % NaCl solution.

Test matrix

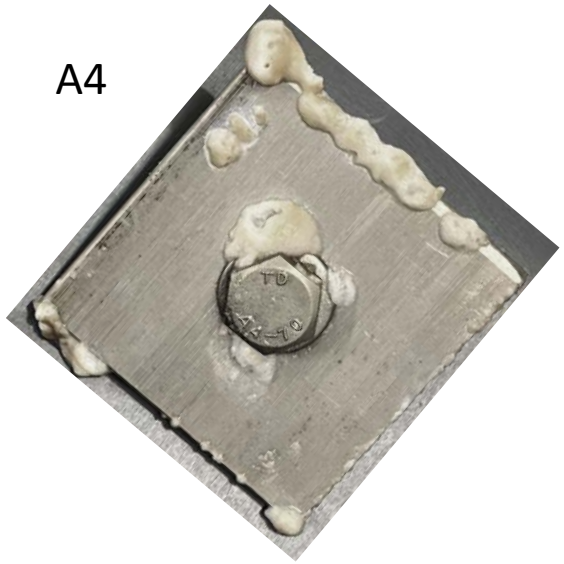
	Alloy	Bolt	Washer
1	6082	A2	A2
2	6082	A4	A4
3	6082	A4	Titanium
4	6082	A4	Aluminium, 5052
5	6082	A4	Anodized 5005, Ø16 mm
6	6082	A4	Anodized 5005, Ø24 mm
7	6082	A4	Nylon, Ø16 mm
8	6082	A4	Nylon, Ø24 mm

Weight loss on 6082 sample and washers

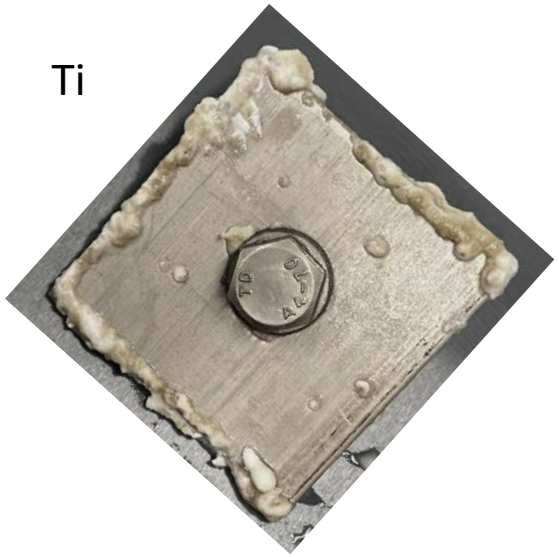


Submerged, without cathodic protection

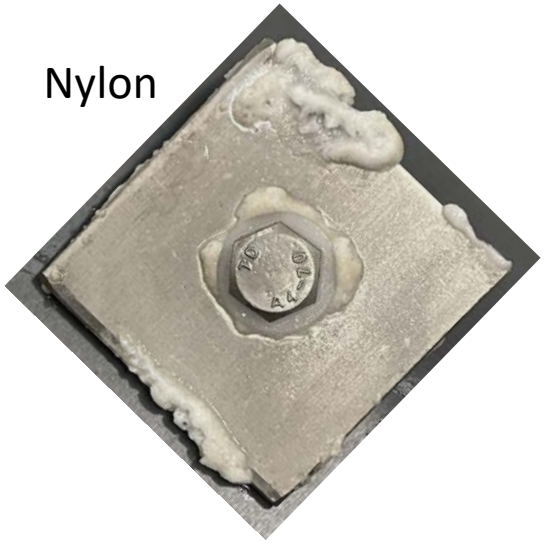
A4



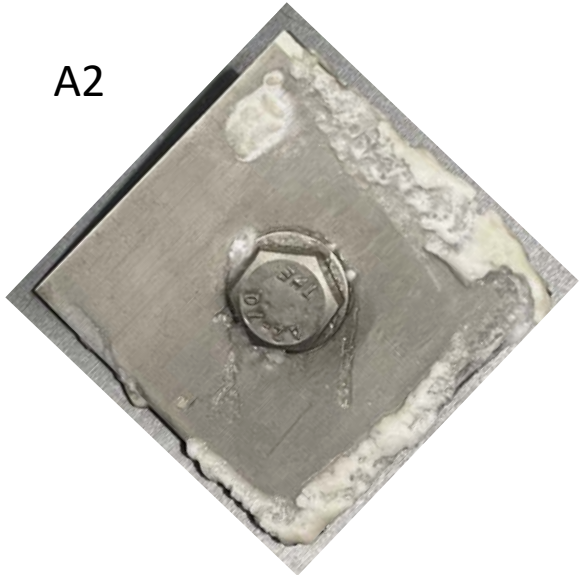
Ti



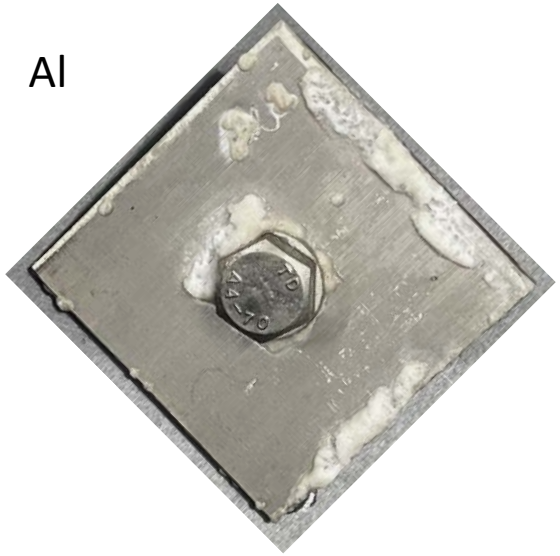
Nylon



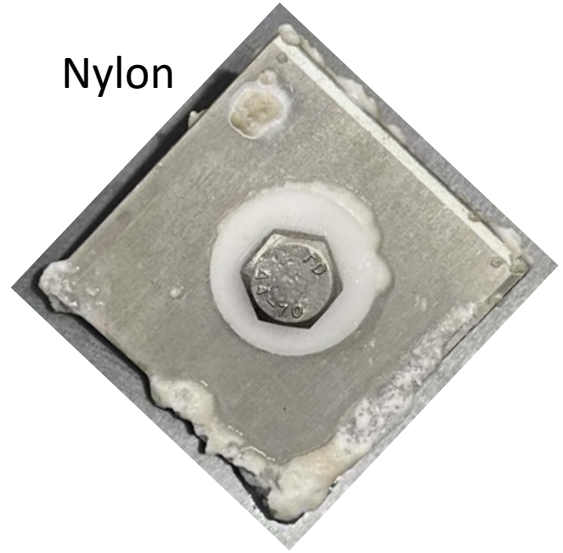
A2



Al



Nylon



Submerged, with CP

A4

Ti

Nylon 16 mm

Anodized 16 mm

A2

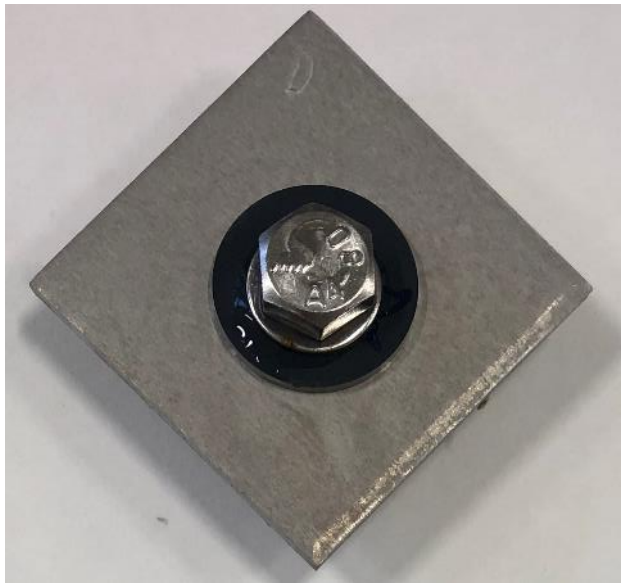
5052

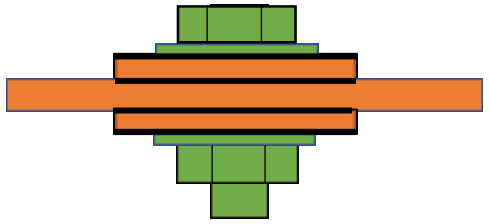
Nylon 24 mm

Anodized 24 mm

Bolted joints with double washers

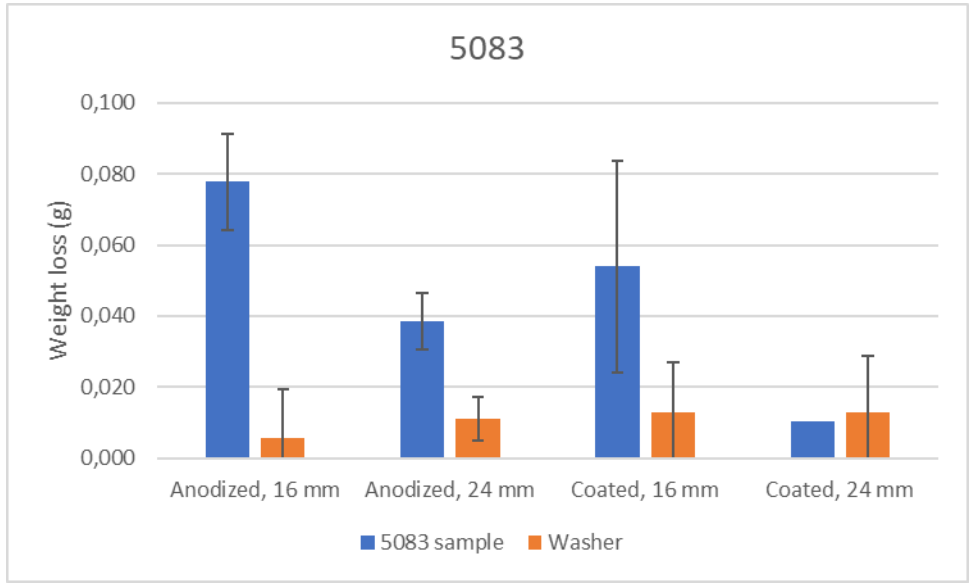
Alloy	Washer material	Diameter
5083	Anodized aluminium	16 mm
		24 mm
	Coated aluminium	16 mm
		24 mm
6082	Anodized aluminium	16 mm
		24 mm
	Coated aluminium	16 mm
		24 mm

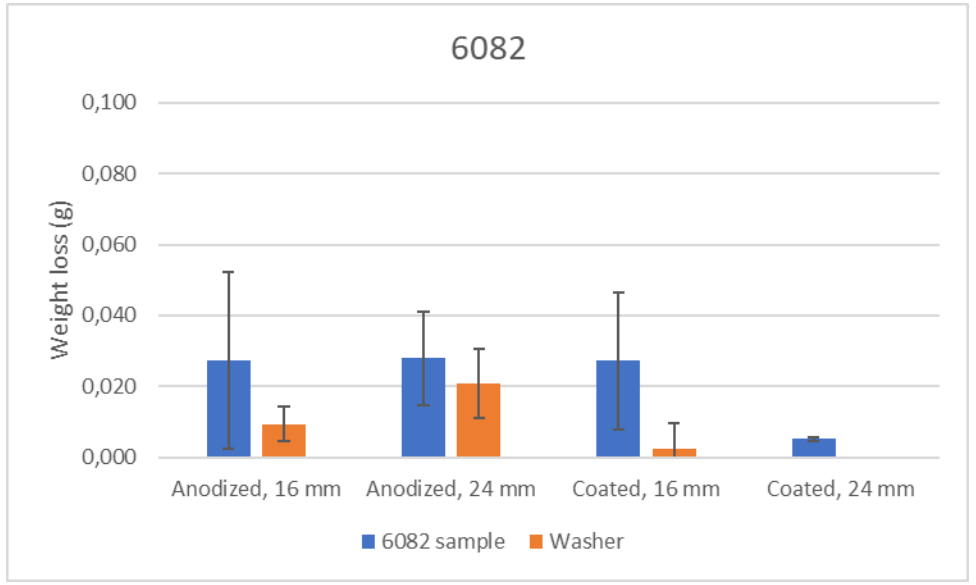




- Corrosion on the panels
  - Generally more corrosion on 5083 than 6082
  - Less corrosion with large coated washers

- Corrosion on the washers
  - The anodizing was crushed along the edge of the A4 washers ➔ galvanic corrosion
  - The coating was penetrated by the A4 washer on some samples ➔ large differences between parallels



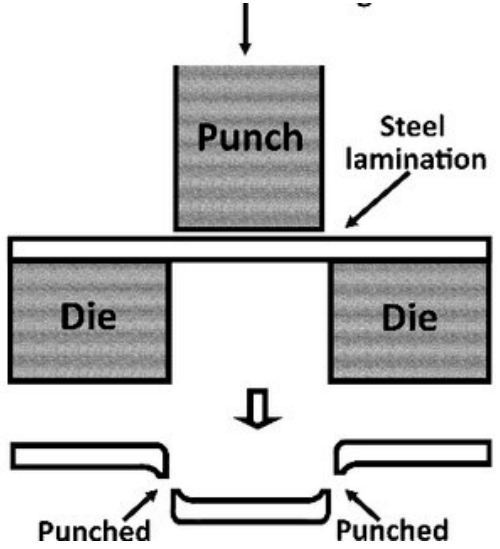


5083, 24 mm anodized washer

24 mm anodized washer

5083, 16 mm anodized washer

24 mm coated washer



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Modelling Galvanic Corrosion

Daniel Höche, Hereon

SINTEF hereon Hydro Muehlhan

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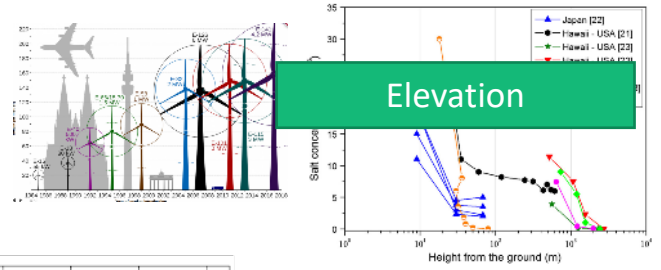
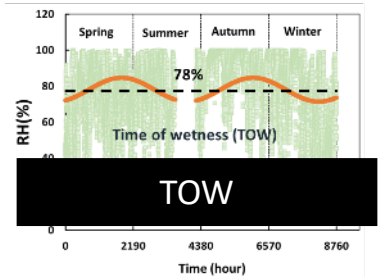
Problem

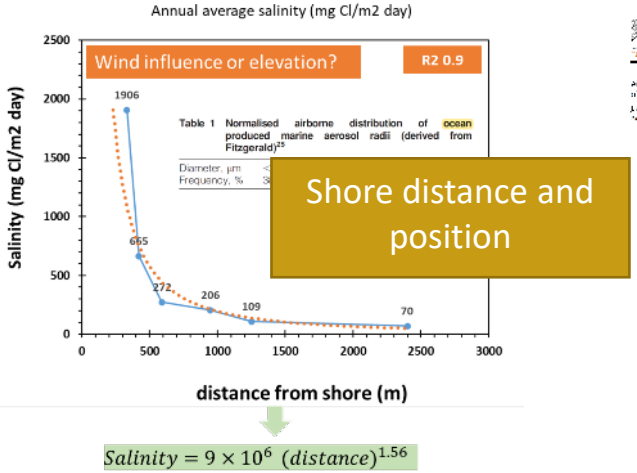


Elevation

Fig. 1. Influence of height from the ground on vertical distribution of salt concentration – literature data.

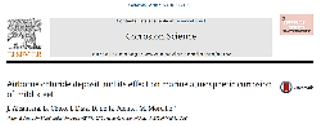


TOW



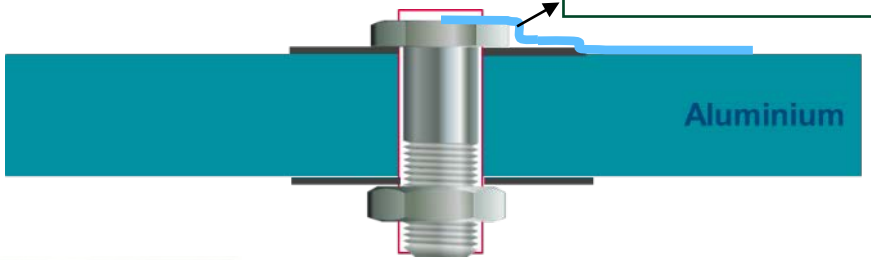
$$Salinity = 9 \times 10^6 \ (distance)^{1.56}$$

Shore distance and position

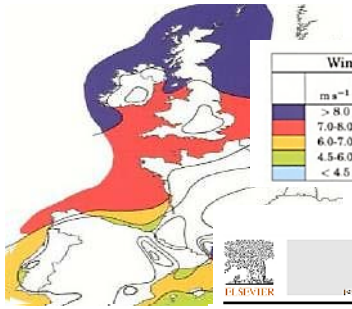


«Sea» parameters

Corrosion conditions?



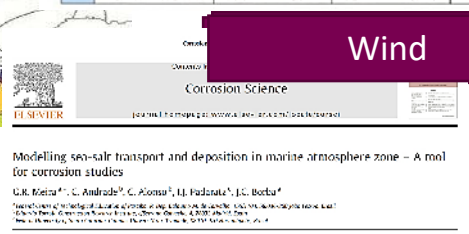
Construction and Materials



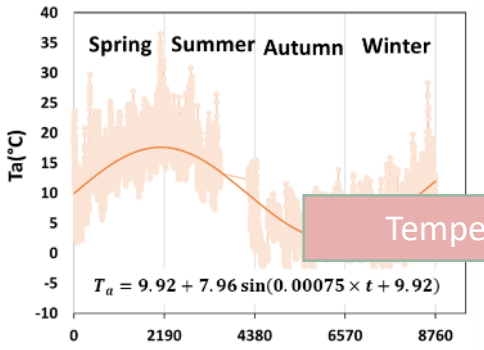
Wind resources over open sea (more than 10 km offshore) for five standard heights

	10 m		25 m		50 m		100 m		200 m	
	m s⁻¹	Wm⁻²	m s⁻¹	Wm⁻²	m s⁻¹	Wm⁻²	m s⁻¹	Wm⁻²	m s⁻¹	Wm⁻²
	> 8.0	> 600	> 8.5	> 700	> 9.0	> 800	> 10.0	> 1100	> 11.0	> 1500
	7.0-8.0	350-600	7.5-8.5	450-700	8.0-9.0	600-800	8.5-10.0	650-1100	9.5-11.0	900-1500
	6.0-7.0	250-300	6.5-7.5	300-450	7.0-8.0	400-600	7.5- 8.5	450- 650	8.0- 9.5	600- 900
	4.5-6.0	100-250	5.0-6.5	150-300	5.5-7.0	200-400	6.0- 7.5	250- 450	6.5- 8.0	300- 600
	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 6.0	< 250	< 6.5	< 300

Wind



Modelling sea-salt transport and deposition in marine atmosphere zone – A mol for corrosion studies



$$T_a = 9.92 + 7.96 \sin(0.00075 \times t + 9.92)$$

Temperature

Task (Corrosion Modelling)

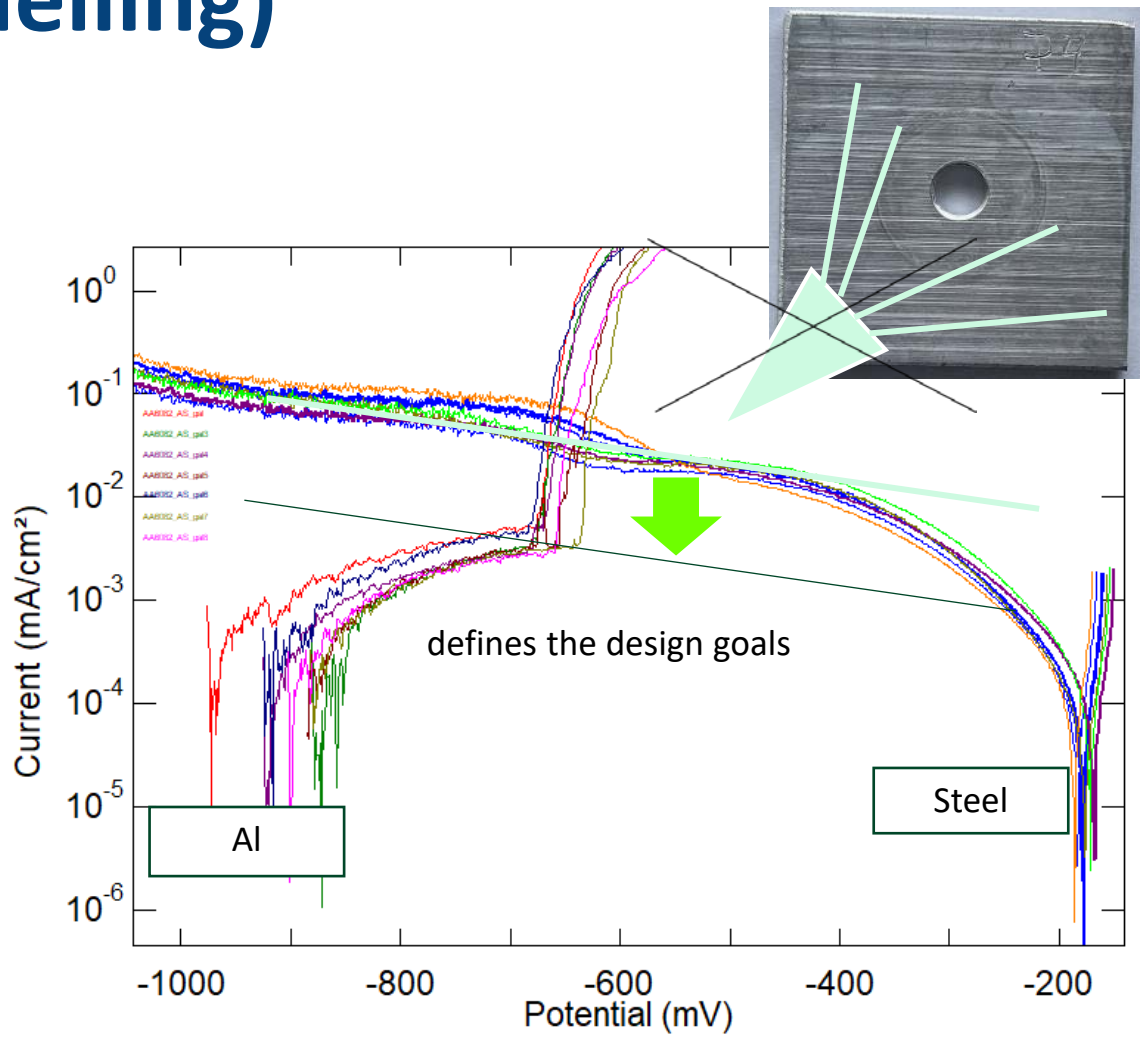
Computational aided Design of bolted Al-steel joints

Requirements / Goal:

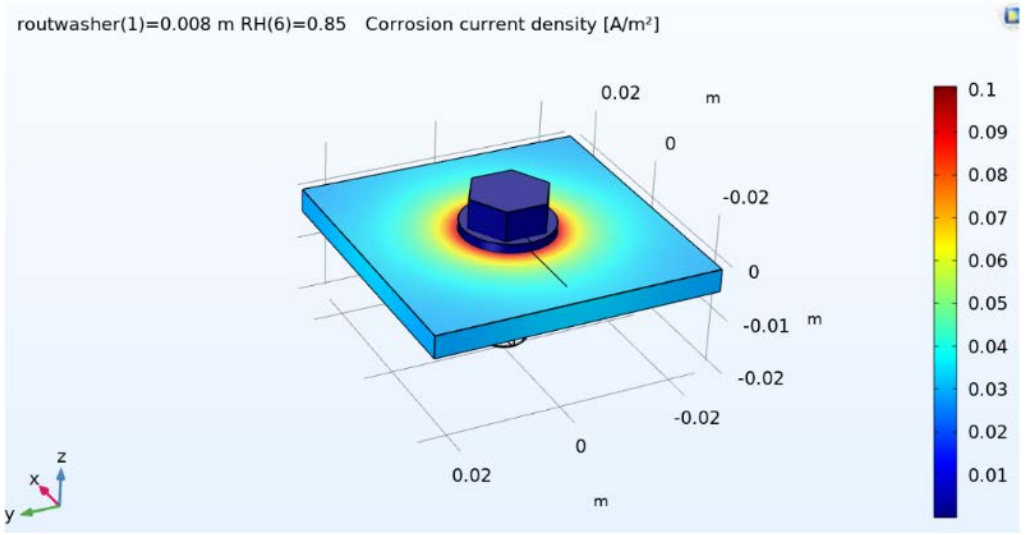
- **Avoid (galvanic) corrosion on Al around the steel**
- Avoid crevice corrosion between Al, washer, steel
- Mechanical strength limits the use of polymers for electrical insulation
- Improve durability of the joint

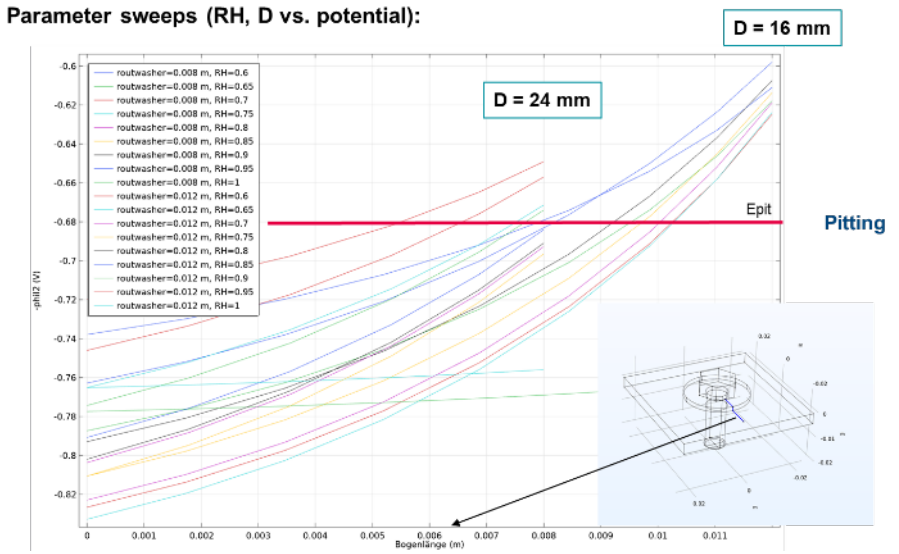
Options:

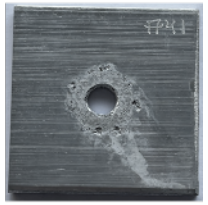
- Materials selection
- Materials modification (e.g. treatments, coatings)
- Joint component system / Joining technology
- Geometry and layout optimization (constructive corrosion protection)



Modelling - physics based



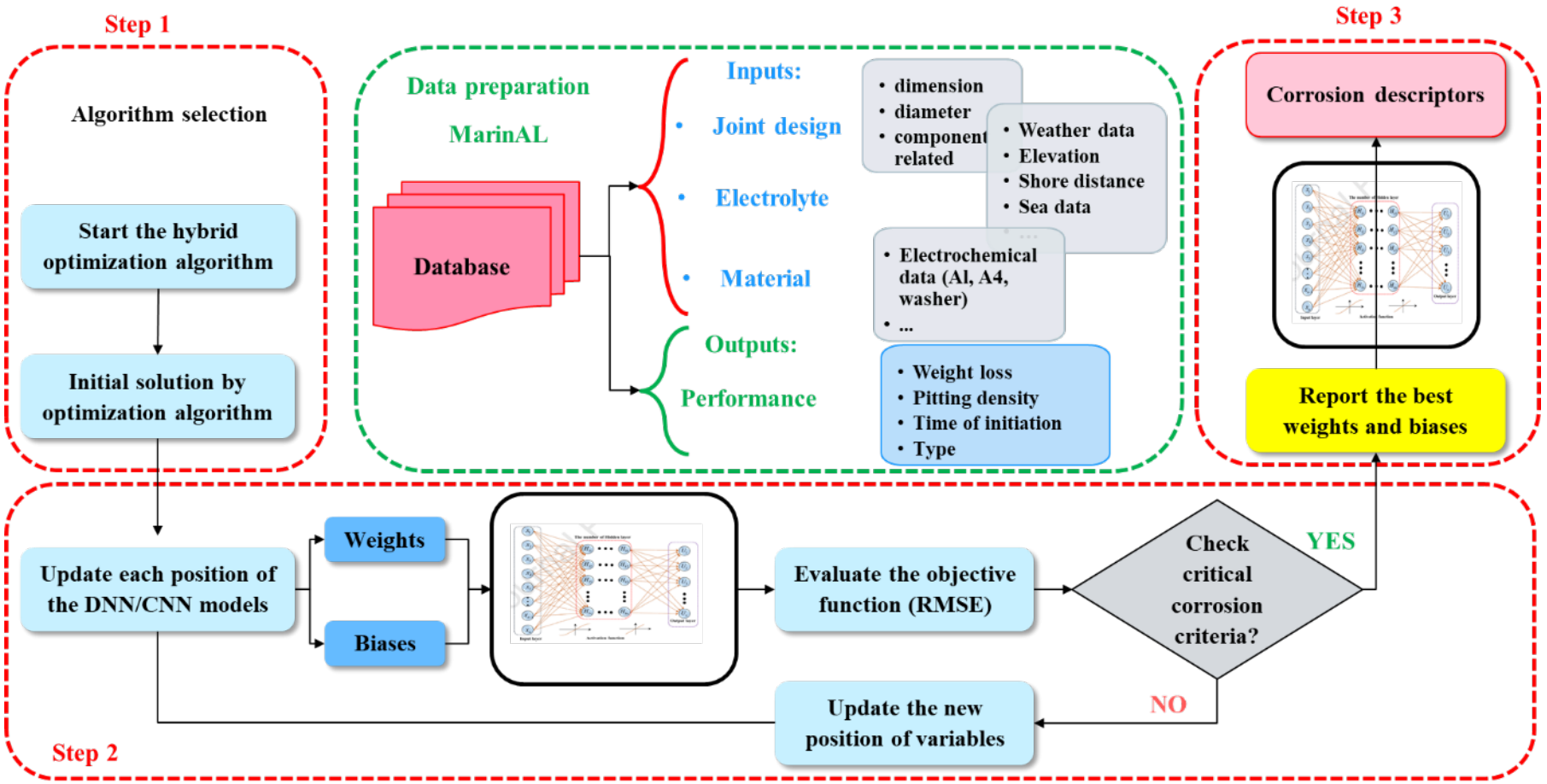




Bad design supports pitting corrosion: (Model vs. Experiment is somehow OK)

Modelling - data based

In progress



Proposed framework for the prediction and classification of atmospheric corrosion in offshore aluminum-steel joints

Lessons learned

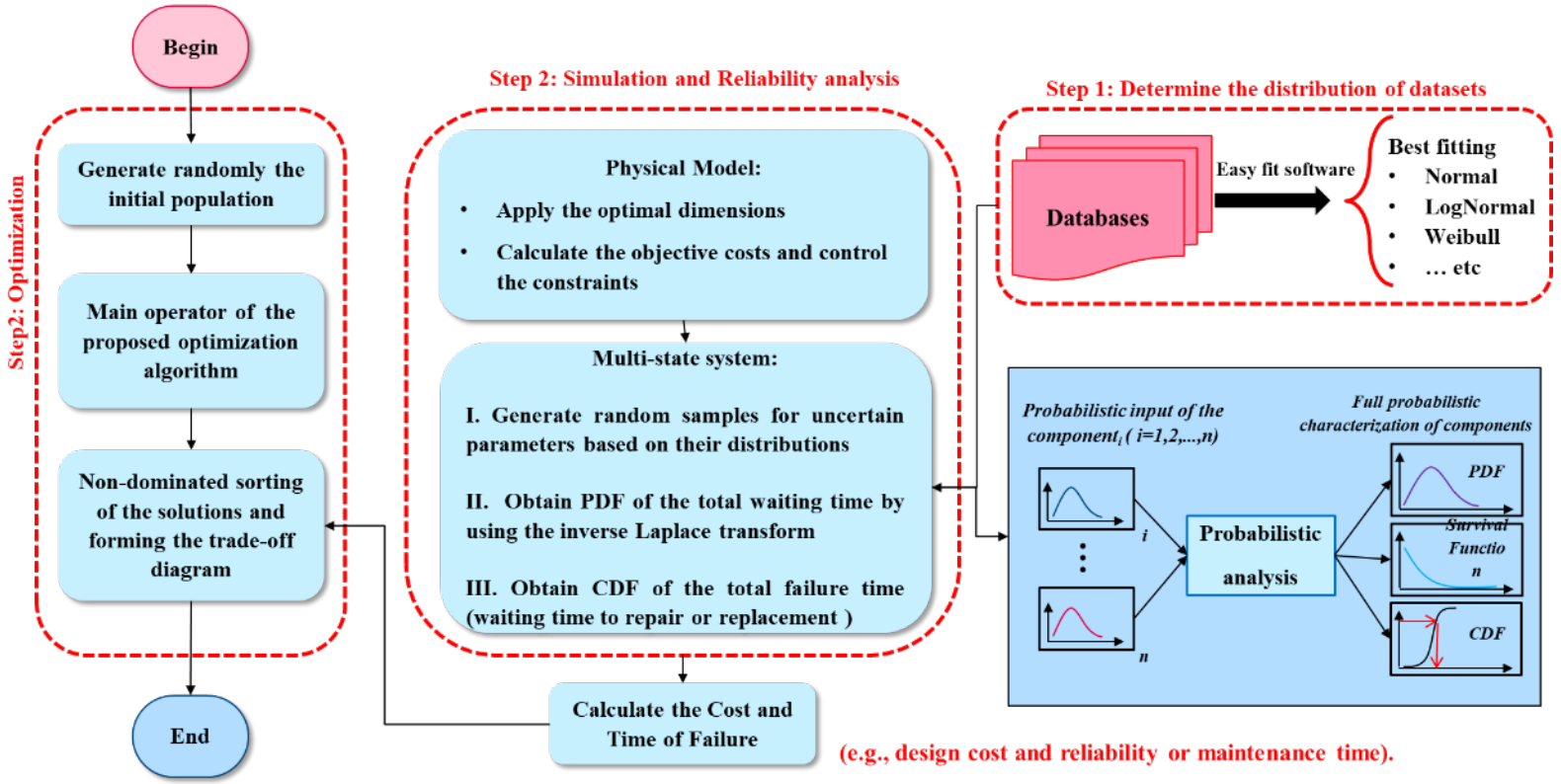
- Avoid an electric potential in the electrolyte film at Al more positive than E_{pit}. (approx. +250 mV vs. OCP for our system currently).
- The washer diameter (16 vs. 24 mm) can lower the max. corrosion current by something like a factor 2. Maximizing this effect requires passivity of the washer.
- The tangential current in the electrolyte film must be minimized. The salt concentration must be lowered especially at the washer.

Design goal: Avoid conductive electrolyte film formation on the washer

- Suppress cathodic activity on the washer

Finally: How to manage at installations / infrastructures?

Reliable industrial application



Digital Management- and Maintenance system

Combing the models: Proposed framework for the reliability based design optimization of offshore aluminum-steel joints