Throwing power of embedded anodes for galvanic cathodic protection of steel in concrete

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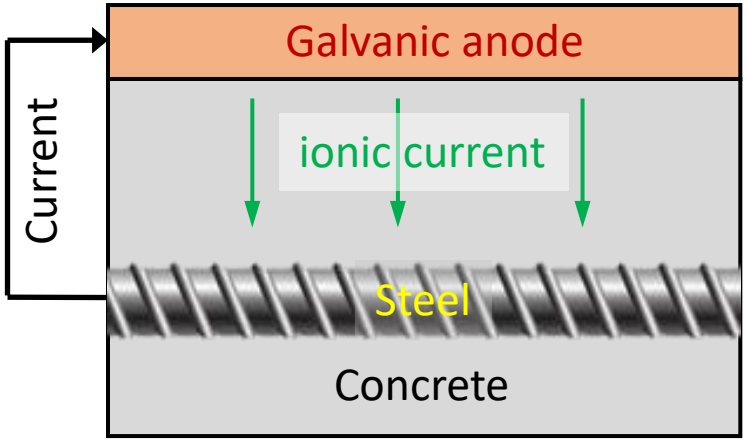
Main durability problem of concrete structures: reinforcement corrosion

Difficult to obtain durable concrete repair by traditional method (i.e. patch repair) due to incipient anode effects and difficulties in identifying all chloride contaminated concrete

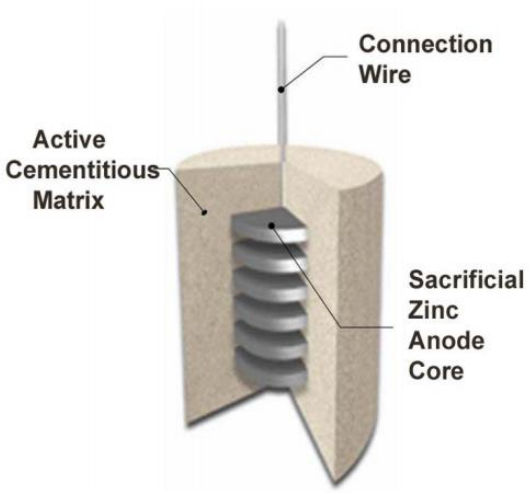
Galvanic Cathodic Protection (GCP) as repair method



$Zn \rightarrow Zn^{2+} + 2e^-$

$1/2O_2 + H_2O + 2e^- \rightarrow 2OH^-$

Discrete embedded anode: GalvaShield CC



VECTOR CORROSION TECHNOLOGIES

Design of a GCP system with discrete anodes

Required amount of zinc

⇩ Determined by

- Reinforcement density
- Estimated galvanic current during intended service life

⇩

Determines **type** of anode to be used (i.e. mass of zinc core)

Throwing power of the anode

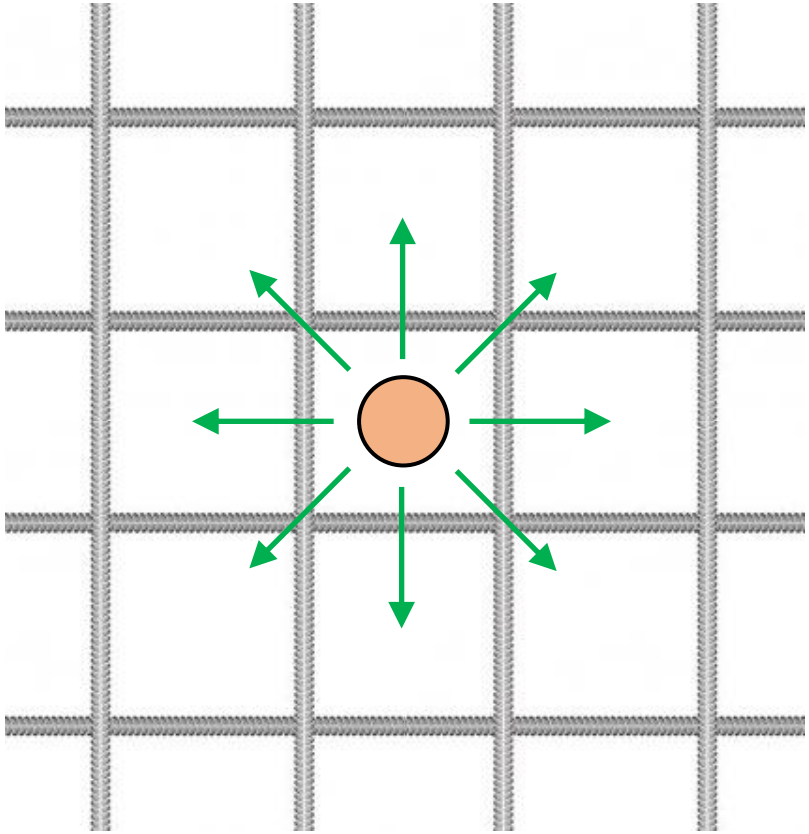
⇩ Influenced by

- Reinforcement density
- Concrete resistance
- Corrosion activity

⇩

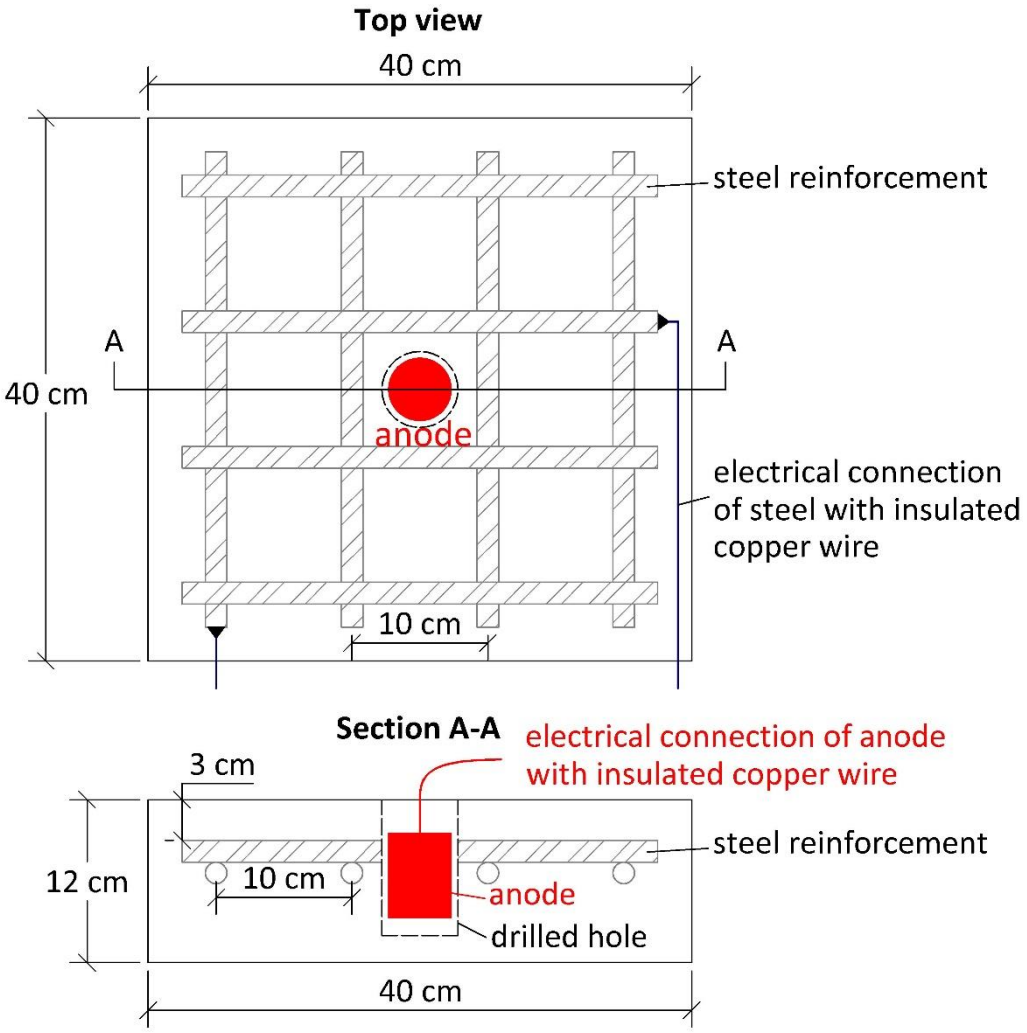
Determines **maximum spacing** between anodes = amount of anodes to be installed

Throwing power (TP) of discrete galvanic anodes



- Method for determination of throwing power (TP)
- Effect of chloride content in concrete on TP
- Influence of environmental conditions on TP

Concrete specimens



- Concrete slabs (400 x 400 x 120 mm)
- Mesh ϕ16 mm ↔ 100 mm = 1 m² steel / m² concrete
- Anode installed in the center of the slab

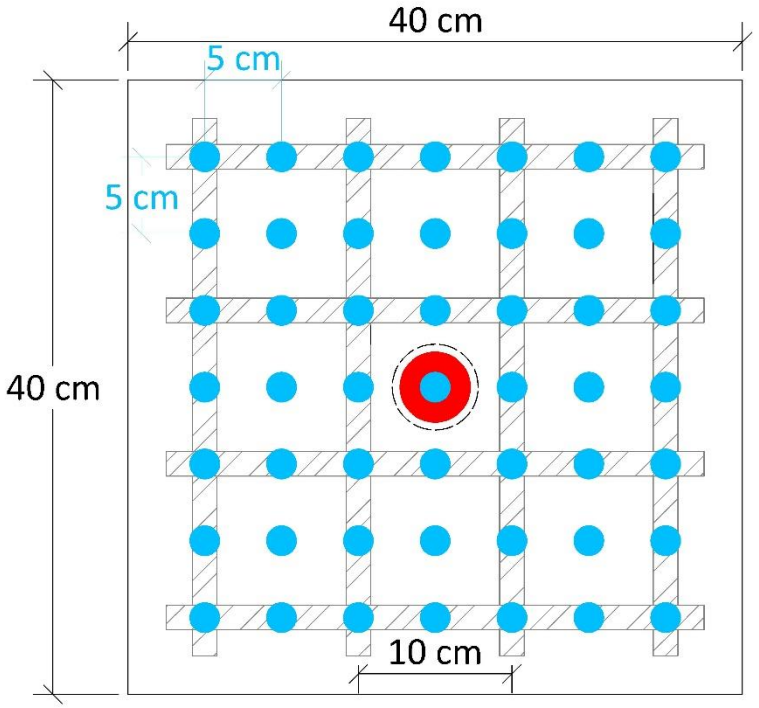
4 concrete mixes with different amount of mixed-in chlorides

- 0 m% NaCl / cement mass
- 0,5 m% NaCl / cement mass
- 1 m% NaCl / cement mass
- 2 m% NaCl / cement mass

Determination of throwing power

THROWING POWER = distance from anode where 100 mV depolarization in 24 hours is obtained

24-hour depolarization is determined by means of potential mappings with an external $Cu/CuSO_4$ electrode



- Before start of depolarization
  = **'ON'** potential
- 4 hours after start of depolarization
  = **'4h OFF'** potential
- 24 hours after start of depolarization
  = **'24h OFF'** potential

Example result of potential mappings

'ON' potential

-91	-139	-178	-180	-185	-151	-109
-139	-177	-222	-205	-231	-177	-152
-163	-253	-390	-499	-337	-219	-187
-177	-227	-432	-828	-469	-220	-163
-162	-196	-298	-444	-377	-214	-169
-120	-154	-171	-196	-195	-175	-166
-118	-146	-137	-146	-176	-154	-155

'4h OFF' potential

-82	-92	-133	-137	-135	-118	-108
-100	-119	-148	-126	-153	-134	-128
-124	-149	-181	-192	-157	-125	-127
-114	-127	-165	-328	-184	-109	-103
-104	-120	-145	-166	-163	-120	-118
-79	-93	-82	-84	-89	-91	-102
-71	-71	-85	-66	-78	-73	-86

'24h OFF' potential

-32	-37	-66	-63	-71	-54	-54
-42	-47	-65	-71	-78	-61	-65
-48	-62	-98	-137	-97	-62	-70
-55	-60	-152	-243	-126	-77	-68
-62	-63	-105	-185	-118	-79	-67
-47	-54	-71	-85	-92	-80	-82
-40	-64	-41	-58	-72	-72	-77

Potential values in mV vs $Cu/CuSO_4$

4h depolarization

9	47	45	43	50	33	1
39	58	74	79	78	43	24
39	104	209	307	180	94	60
63	100	267	500	285	111	60
58	76	153	278	214	94	51
41	61	89	112	106	84	64
47	75	52	80	98	81	69

24h depolarization

59	102	112	117	114	97	55
97	130	157	134	153	116	87
115	191	292	362	240	157	117
122	167	280	585	343	143	95
100	133	193	259	259	135	102
73	100	100	111	103	95	84
78	82	96	88	104	82	78

Depolarization	Color code
< 50 mV	
50 mV – 80 mV	
80 mV – 100 mV	
> 100 mV	

Example of depolarization results

(a) 0 m% NaCl

4h depolarization

92	110	135	116	108	122	103
98	122	153	155	128	118	84
82	120	224	296	223	120	73
87	133	319	549	317	131	93
85	117	245	284	218	111	82
78	86	108	269	101	81	42
65	71	94	89	80	39	38

24h depolarization

143	156	172	157	157	140	142
143	164	183	207	178	159	100
155	211	330	358	283	169	137
131	170	351	634	368	184	121
148	191	289	341	298	190	148
123	148	174	198	174	155	114
109	123	148	135	139	110	89

(b) 0.5 m% NaCl

4h depolarization

9	47	45	43	50	33	1
39	58	74	79	78	43	24
39	104	209	307	180	94	60
63	100	267	500	285	111	60
58	76	153	278	214	94	51
41	61	89	112	106	84	64
47	75	52	80	98	81	69

24h depolarization

59	102	112	117	114	97	55
97	130	157	134	153	116	87
115	191	292	362	240	157	117
122	167	280	585	343	143	95
100	133	193	259	259	135	102
73	100	100	111	103	95	84
78	82	96	88	104	82	78

(c) 1 m% NaCl

4h depolarization

10	27	28	42	34	20	8
33	65	88	160	120	65	17
40	73	191	301	210	110	54
64	121	237	488	371	190	94
81	106	171	245	205	126	116
21	59	90	125	122	100	71
39	39	22	74	63	58	29

24h depolarization

20	46	60	61	60	49	21
54	60	102	159	142	78	38
45	109	207	305	224	108	1
59	130	233	482	383	208	87
75	125	184	200	220	127	111
38	89	106	150	138	107	100
52	65	55	82	83	67	51

(d) 2 m% NaCl

4h depolarization

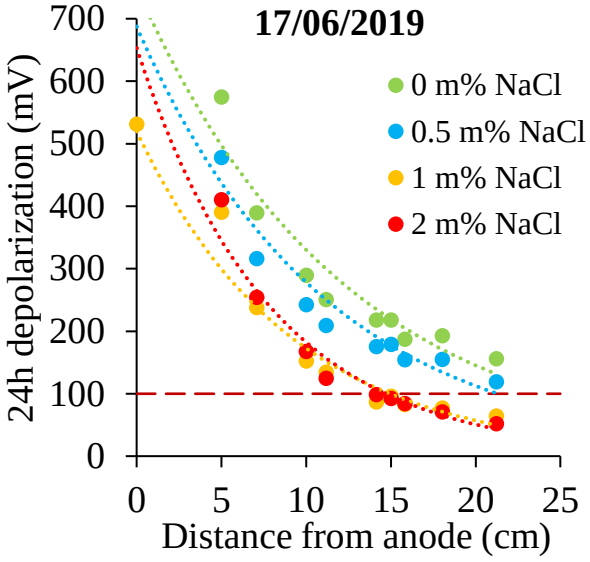
-23	-15	-2	9	18	4	-4
6	27	58	59	43	11	20
26	54	131	221	131	47	30
15	70	226	449	187	65	21
18	61	141	252	140	58	39
27	42	45	44	30	-2	24
-3	3	4	24	26	6	-24

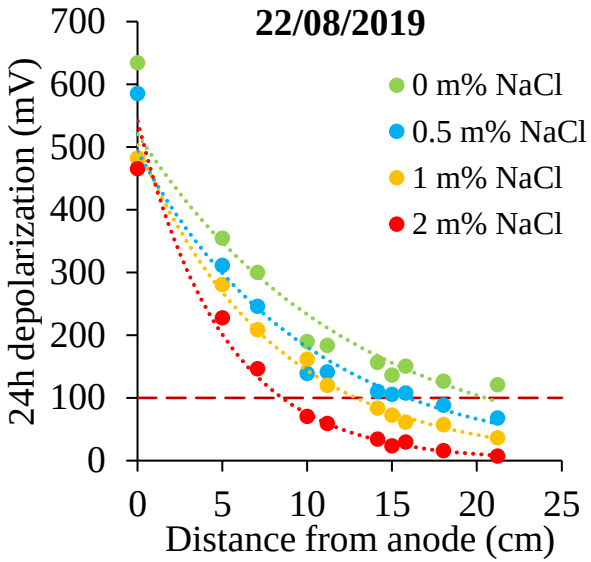
24h depolarization

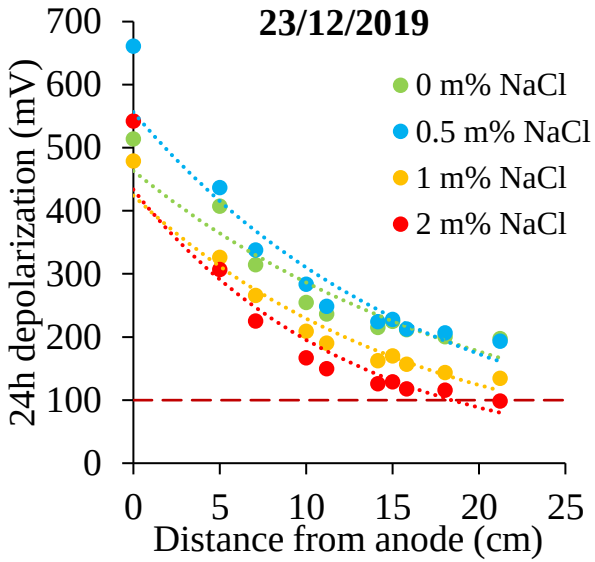
-5	-4	19	32	46	21	18
7	33	74	72	59	28	25
24	55	143	236	153	61	38
18	77	212	465	197	76	10
18	63	139	264	150	72	45
22	47	40	56	47	28	11
10	25	10	34	35	19	5

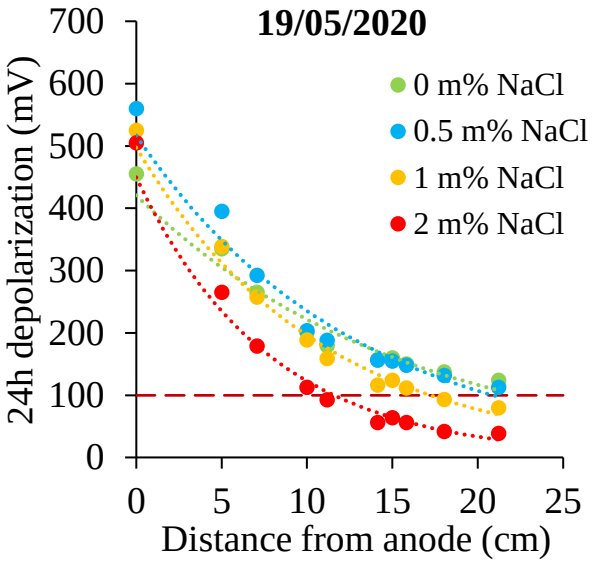
Depolarization is lower when chloride content in the concrete is higher

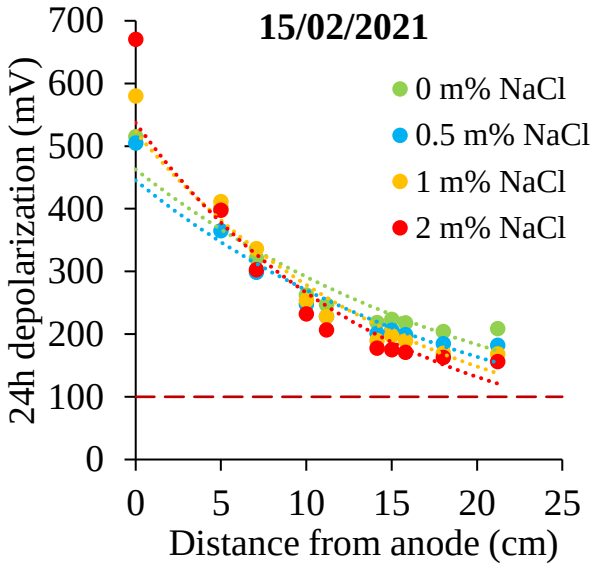
24h depolarization vs. distance from anode



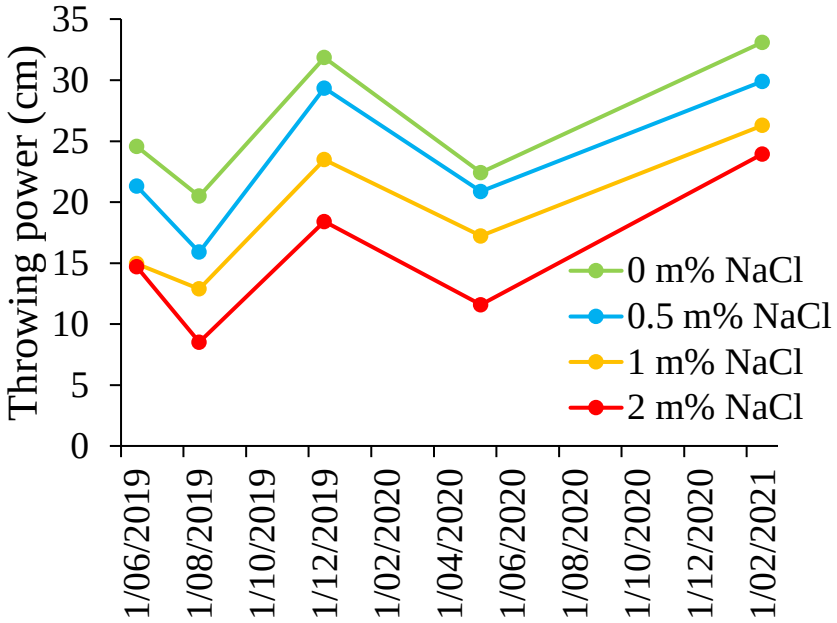


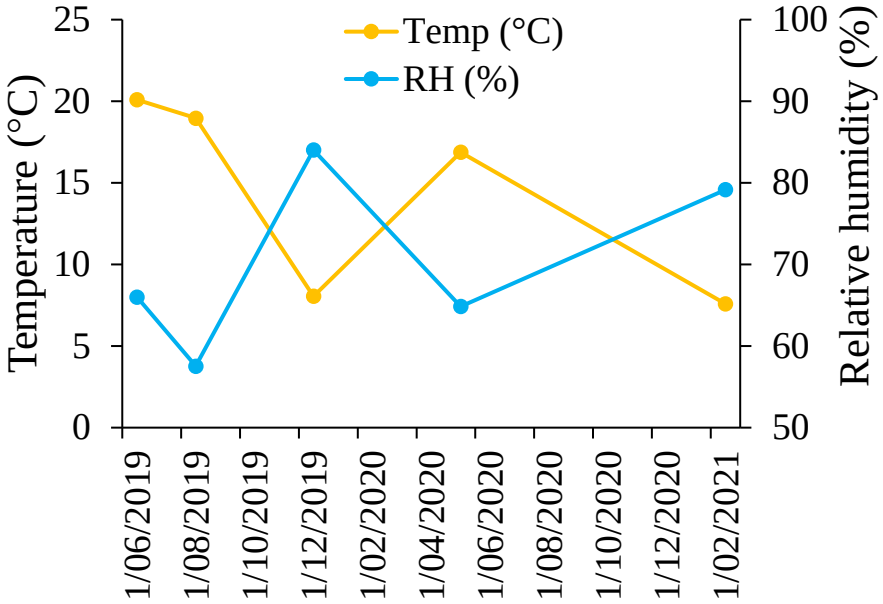




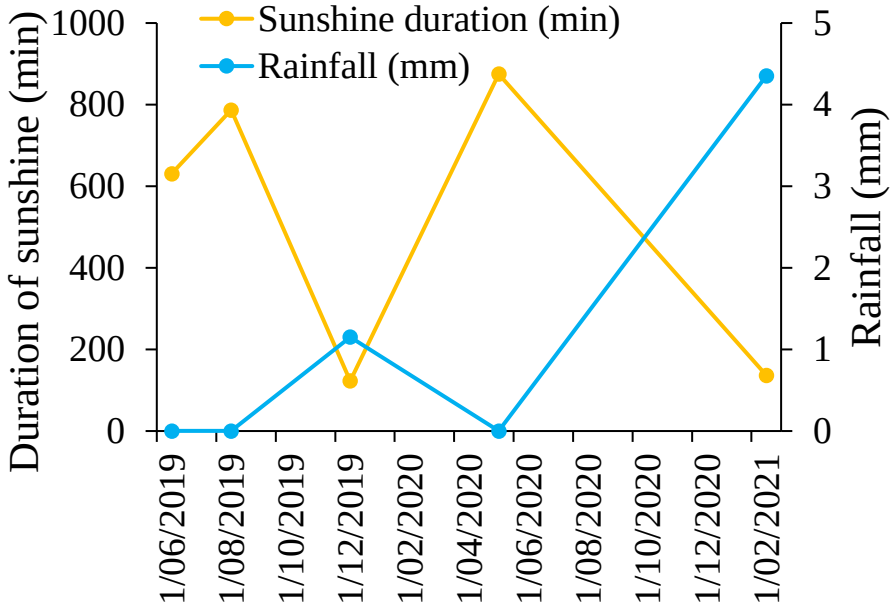


Influence of environmental conditions on TP





- TP ↘ as Cl^- content ↗
- TP ↗ as Temp ↘ and RH ↗
- TP ↗ when rainfall ↗



Throwing power (TP) of discrete galvanic anodes

- Potential mappings around discrete anodes during depolarization allows a detailed determination of TP
- **Throwing power decreases with increasing chloride content**, making the technique more suitable/economical for corrosion prevention than for stopping ongoing corrosion at high chloride concentrations
- **Throwing power varies with environmental conditions** within a range of:
  - 20 – 33 cm (no chlorides in concrete mix)
  - 8.5 – 24 cm (2 m% NaCl by cement mass added)
  - TP is highest in periods with rainfall, high RH (> 80%) and low temperature (< 15˚C)

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