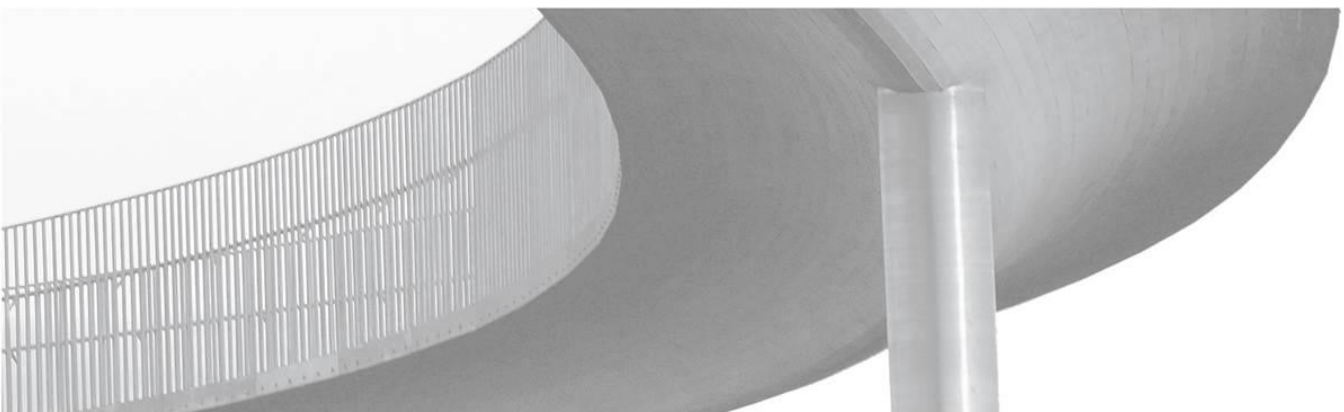


TÆRING Á RYÐFRÍU STÁLI Í ÍSLENSKU SJÁVARUMHVERFI

Áfangaskýrsla 1, niðurstöður eftir eitt ár

17.10.2023



SKÝRSLA – UPPLÝSINGABLAÐ

SKJALALYKILL

2970-247-SKY-006-V01

SKÝRSLUNÚMÉR / SÍÐUFJÖLDI

2970-247-SKY-006/ 23

VERKEFNISSTJÓRI / FULLTRÚI VERKKAUPA

Ólafur Sveinn Haraldsson

VERKEFNISSTJÓRI EFLA

Baldvin Einarsson

LYKILORÐ

Ryðfrítt stál, tæring

STAÐA SKÝRSLU

- Drög
 Drög til yfirlstrar
 Lokið

DREIFING

- Opin
 Dreifing með leyfi verkkaupa
 Trúnaðarmál

TITILL SKÝRSLU

Tæring á ryðfríu stáli í íslensku sjávarumhverfi

VERKHEITI

Tæring á ryðfríu stáli

VERKKAUPI

Rannsóknarsjóður Vegagerðarinnar

HÖFUNDUR

Baldvin Einarsson

ÚTDRÁTTUR

Birtar eru niðurstöður á tæringu á fimm tegundum af ryðfríu stáli eftir eins árs veðrun á Kársnesi í Kópavogi og við Veðurstofu Íslands í Reykjavík. Einnig eru birtar niðurstöður á tæringu á venjulegu stáli á sömu stöðum til samanburðar við fyrri mælingar og til að flokka tæringaraðstæður á mælistöðunum.

Tæring á stálsýnum er mjög í samræmi við eldri mælingar eftir eitt ár. Engin tæring kom fram á sýnum úr ryðfríu stáli eftir eitt ár, en lítilsháttar litabrigði komu fram á einni stáltegund.

ÚTGÁFUSAGA

<u>NR.</u>	<u>HÖFUNDUR</u>	<u>DAGS.</u>	<u>RÝNT</u>	<u>DAGS.</u>	<u>SAMÞYKKT</u>	<u>DAGS.</u>
01	Baldvin Einarsson	17.10.23	Magnús Arason, Brynja Arnardóttir	18.10.23	Baldvin Einarsson	19.10.23

Lýsing

SAMANTEKT

Vorið 2022 voru sett upp sýni úr ryðfríu stáli í tvo tæringarrekkna. Annar þeirra er staðsettur á fyllingu utarlega á Kársnesi í Kópavogi þar sem ráðgert er að byggja brú, Fossvogsbrú, yfir til Reykjavíkur. Hinn tæringarrekkinn er staðsettur við aðsetur Veðurstofu Íslands á Háaleiti í Reykjavík.

Sýnin eru úr fimm mismunandi tegundum af ryðfríu stáli og af einni tegund eru tvö sýni með mismunandi yfirborðáferð, á allt því sex sýni. Stálsýnin voru fengin hjá stálframleiðanda, Outocumpu í Svíþjóð. Flest sýni eru af Duplex stáli en eitt sýni er úr stáli 1.4404 (AISI 316L) sem er algengt stál til nota utandyra hér á landi.

Í hvorum tæringarrekkna voru sett upp tvö sýni af hverri tegund. Annað sýnið er óvarið, þ.e.a.s. undir beru lofti en hitt sýnið er í skjóli í hálflokuðum kassa. Tilgangurinn með þessu fyrirkomulagi er að finna mun á tæringu á stálinu þar sem regn skolar óhreinindum af yfirborðinu annars vegar og hins vegar þar sem skjól er fyrir regni og óhreinindi safnast fyrir.

Til viðbótar voru sett upp sýni af venjulegu byggingarstáli (S235) og hreinu sínki í rekkana til að flokka tæringaraðstæður á mælistöðunum. Þá gafst einnig kostur á að bera þær mælingar saman við eldri mælingar á tæringu á stáli og sínki frá árunum 1999-2017.

Eftir eins árs tæringu í tæringarrekkna eru helstu niðurstöður þessar:

- Tæringarflokkur mælistaðanna er C-3 fyrir Kársnes og C-2 fyrir Veðurstofuna
- Það kom ekki fram munur á tæringu á ryðfríu stáli á mælistöðunum
- Það kom ekki fram munur á tæringu í opnu eða lokuðu rými
- Litabreyting (staining) kom fram í sýnum úr stáli 1.4404 en engin tæring
- Engin litabreyting eða tæring kom fram á öðrum sýnum úr ryðfríu stáli.

Eftir mælingu og skoðun voru sýnin sett aftur upp í tæringarrekkana og standa vonir til að frekari niðurstöður fáiast um tæringu á ryðfríu stáli á komandi árum.

Skýrslan er skrifuð á ensku þar sem stálframleiðandinn, Outocumpu, sem lagði til stálsýnin okkur að kostnaðarlausu óskaði eftir því að fá mæliniðurstöðurnar. Þykir sjálfsagt að verða við því.

Höfundar skýrslunnar bera ábyrgð á innihaldi hennar. Niðurstöður hennar ber ekki að túlka sem yfirlýsta stefnu Vegagerðarinnar eða álit þeirra stofnana eða fyrirtækja sem höfundar starfa hjá.

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1 INTRODUCTION

The winning entry for the Fossvogur Bay Bridge in the Reykjavik metropolitan area between the municipalities of Reykjavik and Kopavogur was a composite bridge made of stainless steel and concrete. Despite the high construction cost of using stainless steel, it turned out that the lower maintenance cost made the initial cost increase minimal in comparison to ordinary constructional steel.

Test on the corrosion of different types of stainless steel have been conducted in our neighbouring countries.¹ However, systematic corrosion tests of stainless steels have not been carried out in Iceland. Therefore it was considered necessary to carry out corrosion tests at the site of the bridge before construction.

Samples of six different types of stainless steel were mounted at two test sites, one at Kársnes close to the end of the proposed bridge across Fossvogur and the other at the Icelandic Meteorological Office (IMO). The second test site was selected to connect the results to previous and ongoing corrosion tests of steel, zinc, aluminum and weathering steel at that site. Samples of structural steel and zinc were also mounted at the sites for comparison.

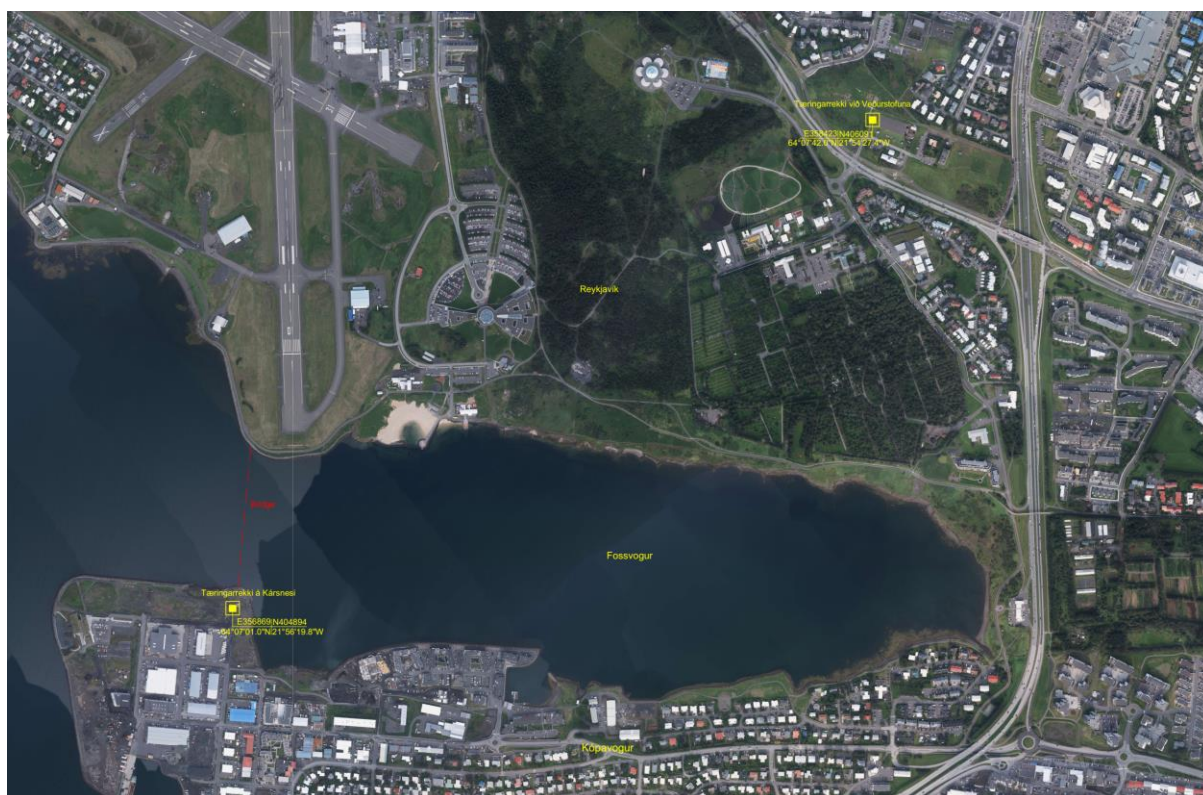
In this memo the results of the corrosion tests after one year exposure are reported. Information on the test sites is given and the corrosion category based on the one year results.

¹ Mameng, Sukanya Hägg and Lena Wegrelius: Atmospheric corrosion Resistance of Stainless Steel in Marine Environment: Results of a Field Exposure Program in Sweden. Report no. 2019_0165 Eurocor conference 2019,

2 THE TEST SITES

TAFLA 1 The location of the test sites.

Site	Local coordinates, ÍSNET93		Global coordinates		HSL [m]
Kársnes	E356869	N404894	64°07'01,0"N	21°56'19,8"W	6
Reykjavík IMO	E358423	N406091	64°07'42,0"N	21°54'27,4"W	60



MYND 1 Test sites.

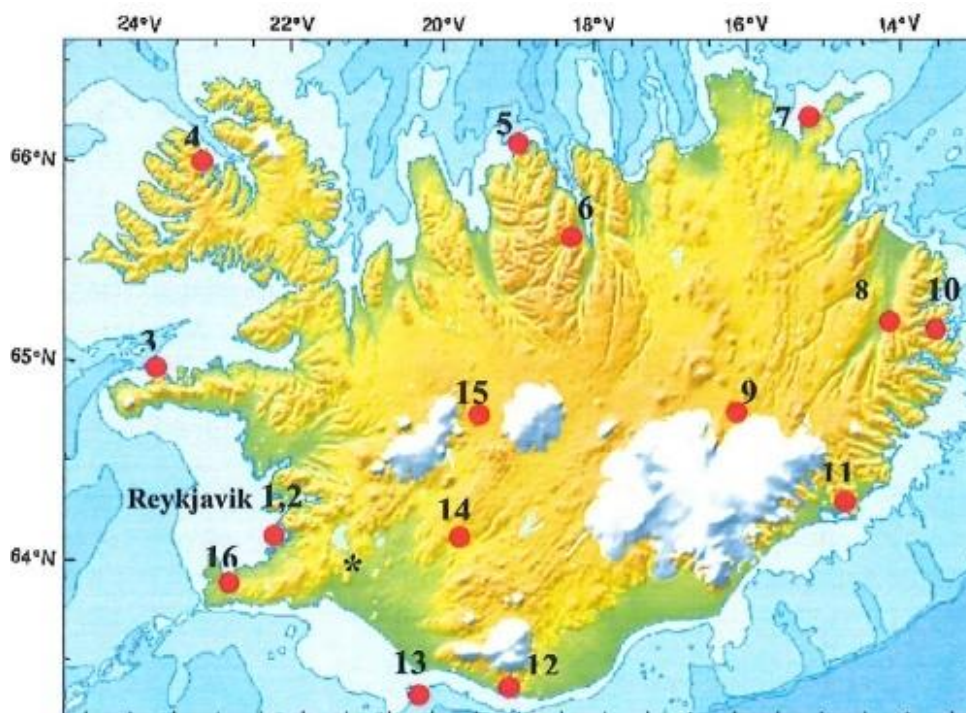
The distance between the test sites is 2 km.

TAFLA 2 Clima characteristics for IMO Reykjavík test station, averages for years 1949-2021.

IMO Reykjavík	Averages for 73 years	Annual range
Average temperature	4,8 °C (average last 20 years 5,4°C)	Max 6,1°C, min 2,8°C
Average relative air moisture	78%	Max 82%, min 74%
Average annual rainfall	826 mm/year	Max 1125, min 560 mm/y
Sunshine hours per year	1308 hours	Max 1587, min 943 hours

3 CORROSION CATEGORY OF TEST SITES

Long term corrosion tests were carried out at 16 test stations around the country during the years 1999-2017. Corrosion of samples of steel, zink and aluminium was measured. Corrosion tests on Weathering steel (Corten Steel) are under way (started 2017) at very much the same stations with 1-5 year results published.²



MYND 2 Test sites in Iceland.

² Hægryðgandi stál. Áfangaskýrsla 5, niðurstöður mælinga eftir 5 ár. Efla, 2023. [NR_1800_651_Hægryðgandi_stál_áfangaskýrsla5.pdf \(vegagerdin.is\)](#)

TAFLA 3 Corrosion after one year at test sites in Iceland, 1999-2000.

ST. NO.	TEST SITE	STEEL		ZINK		AL	
		CORROSION µm/ár	C- CATEGORY	CORROSION µm/ár	C- CATEGORY	CORROSION µm/ár	C- CATEGORY
1	Reykjavík 1	20,8	C-2	2,3	C-4	0,21	C-2
2	Reykjavík 2	18,8	C-2	2,7	C-4		
3	Ólafsvík	22,1	C-2	2,4	C-4		
4	Bolungarvík	14,7	C-2	1,8	C-3	0,15	C-2
5	Siglufjörður	15,5	C-2	1,4	C-3		
6	Akureyri	8,44	C-2	1,5	C-3	0,18	C-2
15	Hveravellir	4,14	C-2	2,2	C-4		
7	Þórshöfn	18,5	C-2	5,0	C-5*		
9	Kverkfjöll	1,37	C-1	1,4	C-3		
8	Egilsstaðir	6,7	C-2	2,4	C-4		
10	Neskaupsstaður	12,5	C-2	3,8	C-4	0,17	C-2
11	Höfn	27,8	C-3	1,6	C-3		
12	Vík	21,6	C-2	2,3	C-4	0,20	C-2
13	Vestmannaeyjar	34,0	C-3	2,0	C-3		
14	Búrfell	22,3	C-2	2,7	C-4	0,36	C-2
16	Svartsengi	47	C-3	2,6	C-4		

Test site Reykjavík 2 is 7,5 km east of test site Reykjavík 1 (IMO), i.e more inland. Only one test site, no. 16 Svartsengi, is considered to have significant SO₂ exposure as it is in the vicinity of a geothermal power station.

According to ÍST EN ISO 9223:2012 (Corrosion of metals and alloys - Corrosivity of atmospheres - Classification, determination and estimation) the corrosion category for Reykjavík is C2 for steel and C4 for zink. This is based on first year corrosion rates (year 1999-2000).

4 FIELD TESTS 2022-2023

Samples of 6 types of stainless steel were mounted on test racks at the two test sites. In addition samples of structural steel (S235) and zink were mounted on the test racks for reference. Each test rack was divided in two; on one side the samples were uncovered, but on the other side the samples were shielded from direct rain.

The test racks were inclined 45°vertically and directed towards open sea, the Kársnes rack to the west and the Reykjavík (IMO) rack to the south. The Kársnes rack is exposed to the sea on three sides.

TAFLA 4 Samples at test sites.

ID	EN TYPE	OUTOCUMPU NAME	SURFACE	NO.	PREN	NOTES
A	1.4404	Supra 316L/4404	1E	4	24	Commonly used outdoors in Iceland
B	1.4362	Forta EDX 2304	2E	4	28	Steel in bridge columns in Reykjavík
C	1.4662	Forta LDX 2404	2E	4	34	
D	1.4462	Forta DX 2205	2E	4	35	Common Duplex steel
E	1.4462	Forta DX 2205	2E Brushed	4	35	Same steel, different surface
F	1.4410	Forta SDX 2507	2E	4	43	Duplex stál in highest CRC
G	Steel S235			3x4		Structural steel for reference
H	Zink			2x4		Zink for reference

The samples were mounted on 20.5.2022 and retrieved on 24.5.2023 after one year and 4 days exposure.



MYND 3 Test sites, Kársnes on the left, Reykjavík IMO on the right.

The stainless steel samples were cleaned with detergent and fresh water. The steel samples were cleaned of rust according to ÍST EN ISO 8407. The zink samples were cleaned with fresh water.

5 RESULTS AFTER ONE YEAR EXPOSURE

5.1 Steel and zink samples

TAFLA 5 Results of tests on steel and zink after one year exposure.

ST. NO.	TEST SITE	STEEL			ZINK	
		CORROSION $\mu\text{m}/\text{year}$	C-CATEGORY	CORROSION $\mu\text{m}/\text{year}$	C-CATEGORY	
1	Kársnes	open	29,3	C-3	*	
		shielded	39,8	C-3	*	
2	Reykjavík IMO	open	19,3	C-2	*	
		shielded	20,5	C-2	*	

*The results for corrosion of the zinc samples are not significant.

The results for the Reykjavík IMO test site are very much in line with previous results in table 3. The seaside location, Kársnes, is giving approx. 50% higher values for corrosion of steel, higher than the highest values obtained at the seaside test sites in the table (11, 12 and 13).

5.2 Stainless steel samples

The stainless steel samples were evaluated by two independent observers and the rating is shown in table 6 for the Kársnes site and table 7 for the Reykjavík IMO site. The rating is according to draft ISO International Standard ISO/DIS 23721:2021³ which is under review and comment.

Each of the specimens were rated by comparing the surface to a photographic standard with 10 different stages of rust from 0% to 100%. Each of these photos is assigned a rating number (RN) from 0 to 9. RN0 corresponds to when the total area of rust and stains cover almost 100% of the sample and RN9 corresponds to when rust and stains cover less than 0,01%. Where the rating of the two

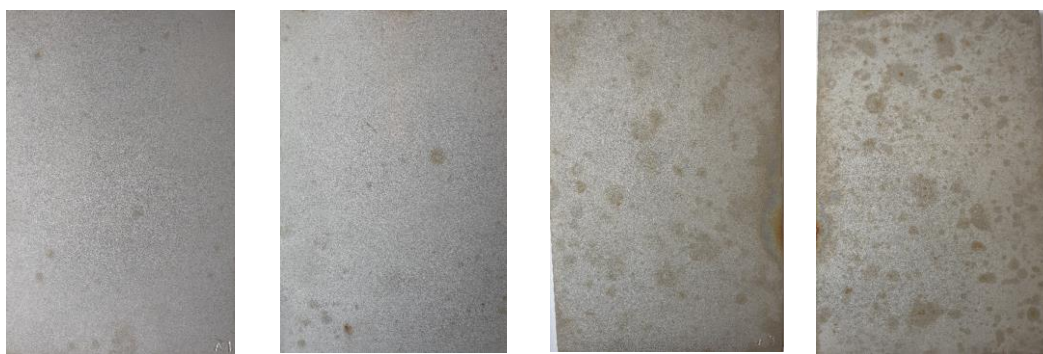
³ ISO/DIS 23721:2021: Corrosion of metals and alloys – Rating method by appearance of rust and stains of atmospheric corrosion for stainless steels.

persons where not identical and an average could not be calculated, the rating numbers of both individuals are indicated such RN9/8 in the table below.

TAFLA 6 Kársnes. Test results after one year exposure.

Stainless steel grade	Type of specimens	Surface finish	Result after 12 months					
			Open condition			Sheltered condition		
			Sample ID	Corrosion performance	Appearance rating	Sample ID	Corrosion performance	Appearance rating
1.4404 Supra 316L	Plate	1E	A1f	No corrosion* Minor staining	RN8/9	A3f	No corrosion* Minor staining	RN8/7
		1E	A1b	No corrosion Minor staining	RN8/9	A3b	No corrosion Minor staining	RN8/7
1.4362 Forta EDX 2304	Plate	2E	B1f	No corrosion No staining	RN9	B3f	No corrosion No staining	RN9
		2E	B1b	No corrosion No staining	RN9	B3b	No corrosion No staining	RN9
1.4662 Forta LDX 2404	Plate	2E	C1f	No corrosion No staining	RN9	C3f	No corrosion No staining	RN9
		2E	C1b	No corrosion No staining	RN9	C3b	No corrosion No staining	RN9
1.4662 Forta LDX 2405	Plate	2E	D1f	No corrosion No staining	RN9	D3f	No corrosion No staining	RN9
		2E	D1b	No corrosion No staining	RN9	D3b	No corrosion No staining	RN9
1.4662 Forta LDX 2405	Plate	2E br.	E1f	No corrosion No staining	RN9	E3f	No corrosion No staining	RN9
		2E br.	E1b	No corrosion No staining	RN9	E3b	No corrosion No staining	RN9
1.4410 Forta SDX 2507	Plate	2E	F1f	No corrosion No staining	RN9	F3f	No corrosion No staining	RN9
		2E	F1b	No corrosion No staining	RN9	F3b	No corrosion No staining	RN9

Note: Axf = front side of plate, Axb = back side of plate. Green cell = no corrosion (pitting) was observed, Red cell = corrosion was observed, * = Possibly some small pits. RN9/8 = results of two independent assessments.



A1 (1)

A1 (2)

A3 (1)

A3 (2)



B1 (1)



B1 (2)



B3 (1)



B3 (2)



C1 (1)



C1 (2)



C3 (1)



C3 (2)



D1 (1)



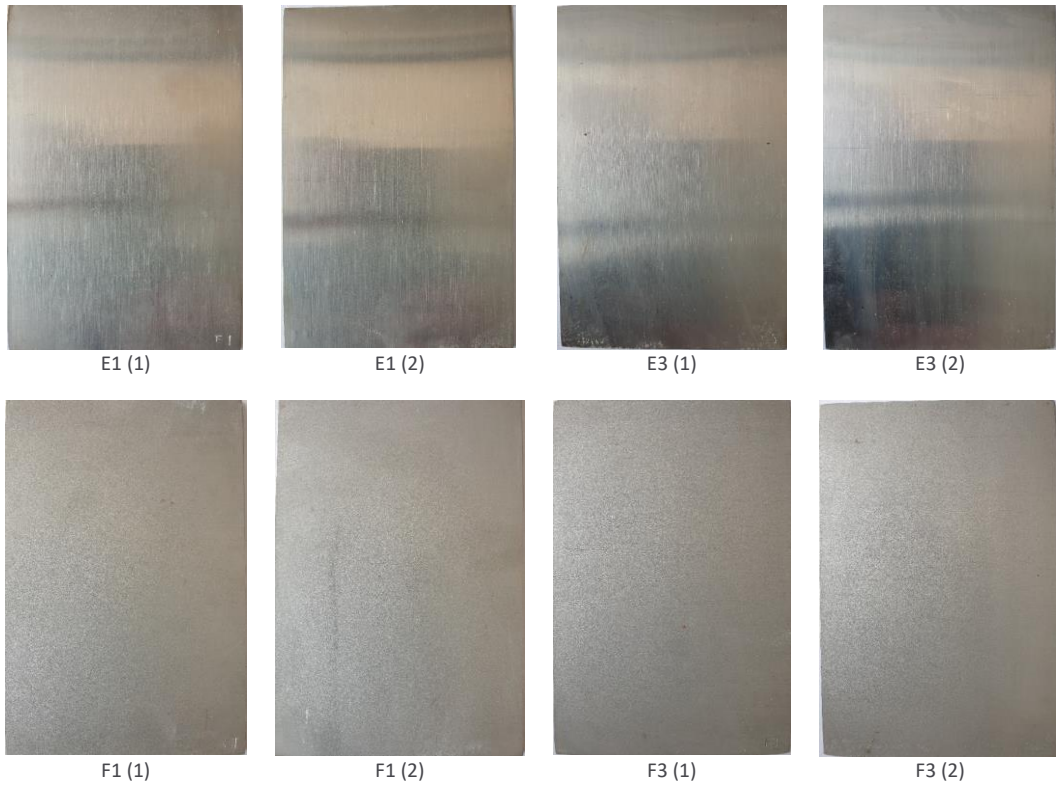
D1 (2)



D3 (1)



D3 (2)

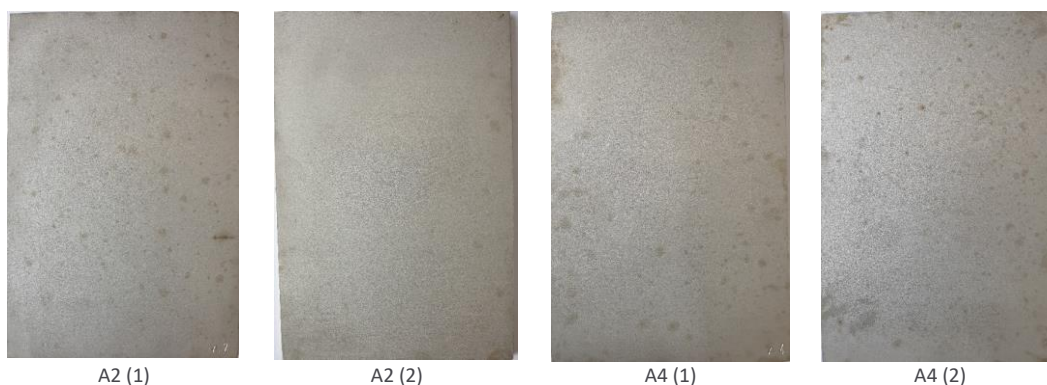


MYND 4 Kársnes, the appearance of plate specimens after 12 months of exposure. Left: open condition, right: sheltered condition. (1) refers to front of specimen, (2) refers to back side of specimen.

TAFLA 7 Reykjavík IMO. Test results after one year exposure.

Stainless steel grade	Type of specimens	Surface finish	Result after 12 months					
			Open condition			Sheltered condition		
			Sample ID	Corrosion performance	Appearance rating	Sample ID	Corrosion performance	Appearance rating
1.4404 Supra 316L	Plate	1E	A2f	No corrosion* Minor staining	RN8	A4f	No corrosion* Minor staining	RN8
		1E	A2b	No corrosion Minor staining	RN8	A4b	No corrosion Minor staining	RN8
1.4362 Forta EDX 2304	Plate	2E	B2f	No corrosion No staining	RN9	B4f	No corrosion No staining	RN9
		2E	B2b	No corrosion No staining	RN9	B4b	No corrosion No staining	RN9
1.4662 Forta LDX 2404	Plate	2E	C2f	No corrosion No staining	RN9	C4f	No corrosion No staining	RN9
		2E	C2b	No corrosion No staining	RN9	C4b	No corrosion No staining	RN9
1.4662 Forta LDX 2405	Plate	2E	D2f	No corrosion No staining	RN9	D4f	No corrosion No staining	RN9
		2E	D2b	No corrosion No staining	RN9	D4b	No corrosion No staining	RN9
1.4662 Forta LDX 2405	Plate	2E br.	E2f	No corrosion No staining	RN9	E4f	No corrosion No staining	RN9
		2E br.	E2b	No corrosion No staining	RN9	E4b	No corrosion No staining	RN9
1.4410 Forta SDX 2507	Plate	2E	F2f	No corrosion No staining	RN9	F4f	No corrosion No staining	RN9
		2E	F2b	No corrosion No staining	RN9	F4b	No corrosion No staining	RN9

Note: Axf = front side of plate, Axb = back side of plate. Green cell = no corrosion (pitting) was observed, Red cell = corrosion was observed, * = Possibly some small pits.





B2 (1)



B2 (2)



B4 (1)



B4 (2)



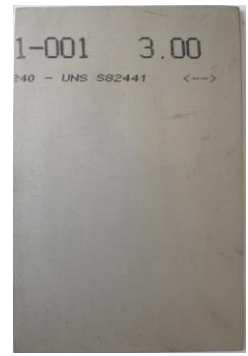
C2 (1)



C2 (2)



C4 (1)



C4 (2)



D2 (1)



D2 (2)



D4 (1)



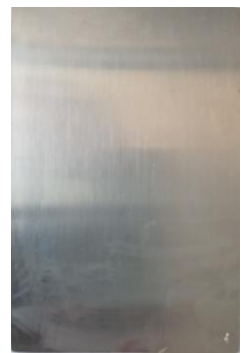
D4 (2)



E2 (1)



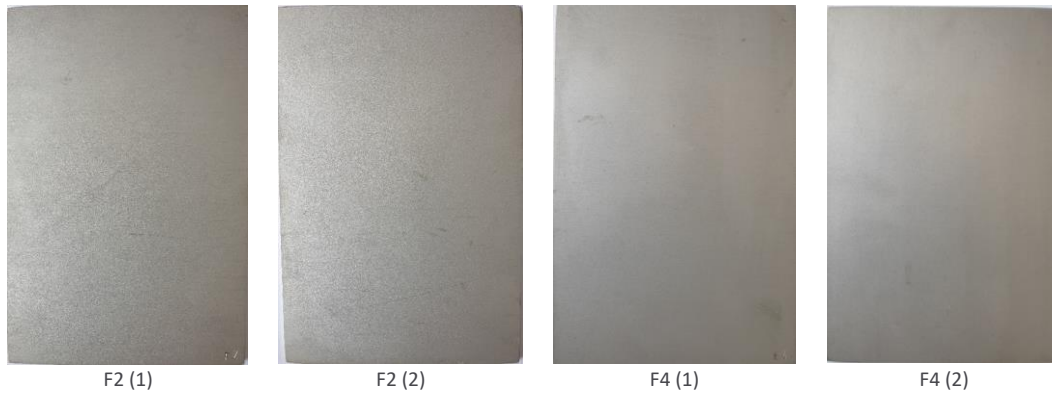
E2 (2)



E4 (1)



E4 (2)



MYND 5 Reykjavik IMO, the appearance of plate specimens after 12 months of exposure. Left: open condition, right: sheltered condition. (1) refers to front of specimen, (2) refers to back side of specimen.

The results after one year exposure of the stainless steel samples can be summarized as follows:

- There is no visible difference of samples from the two test sites.
- There is no visible difference of samples in open air or sheltered conditions.
- Some staining was observed on samples of steel 1.4404 but no corrosion. There may be some small pits.
- No staining or corrosion was observed on any other steel samples.