Business from technology

Characterisation of probe test samples exposed to BLRB lower furnace environments

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Test materials

Material	%C	%Mn	%Si	%Cr	%Ni	%Mo	%Fe	%Cu	Other
Carbon steel									
P265GH	≤0.2	0.80 - 1.40	≤0.40	≤0.30	≤0.30	≤0.08	bal.	≤0.30	
Austenitic stainless steels									
3R12 [304L]	≤0.02	1.3	0.4	18.5	10.5	...	bal.	...	
3RE28[A)] [310]	0.023	1.77	0.39	25.6	21.0	0.06	bal.	0.06	
3xRE28 [A)]	0.012	1.63	0.35	25.2	21.3	0.25	bal.	0.14	
High nickel alloys									
Sanicro 28 [UNS N08028]	≤0.02	≤2.0	≤0.6	27	31	3.5	bal.	1.0	
Sanicro 38 [mod. 825]	≤0.03	0.8	≤0.5	20	38.5	2.6	bal.	1.7	Ti: 0.8
HR11N	0.03	2.0	0.6	27.0	38	0.5 - 1.5	bal.		N: 0.1
Nickel base alloys									
Sanicro 67 [Alloy 690]	0.02	≤0.5	≤0.5	30	60	...	bal.	...	Co: <0,05
Super 625	0.1	≤0.5	≤0.5	20 -23	bal.	...	≤5.0	...	W: 3.15-4.15 Al: 0.4 Co ≤ 1.0

A) Tube samples analysed by VTT

Corrosion resistance evaluation – Procedures

A. Wall thickness measurements before and after testing (corrosion rate)

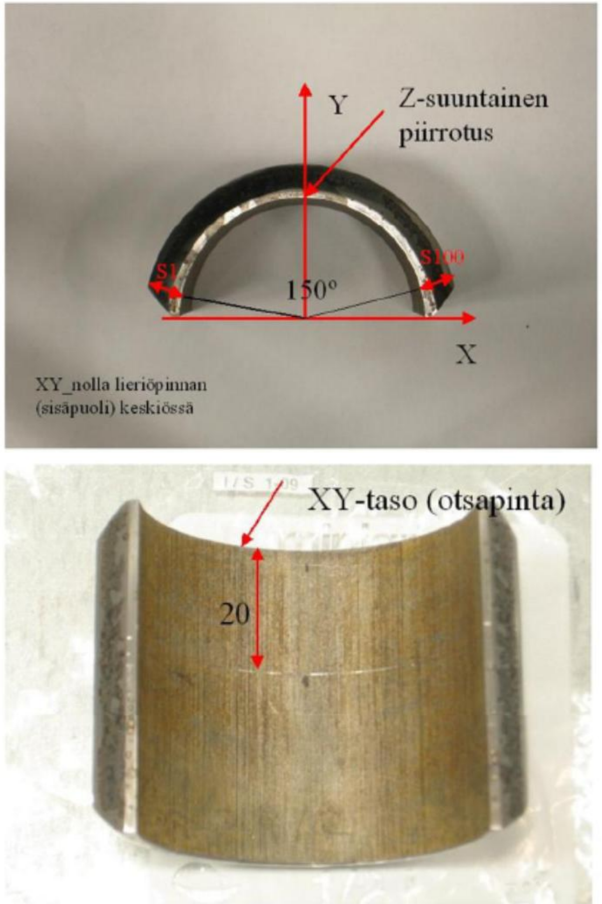
- Thickness profiles at a function of circumference from three locations (axial direction)
  → average & maximum WT losses

B. Characterisation and corrosion mechanism

- SEM/EDS from metallographic cross sections after/before the profile measurements
- Few analysis also from unexposed reference samples

✓ Tests No.1…3 - Materials tested in as received condition

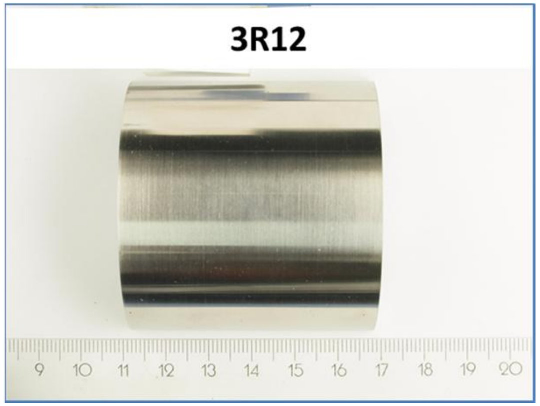
✓ Tests No.4 and 5 - The outer and inner surfaces machined and hand grinded/polished

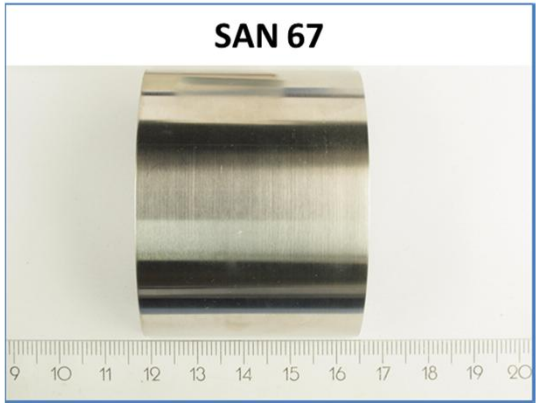


Measurements with coordinate measurement machine

Corrosion resistance evaluation – Procedures

Probe No. 2 – Specimens tested in as received condition





Probe No. 4 - Surfaces machined and hand grinded/polished

Test matrix

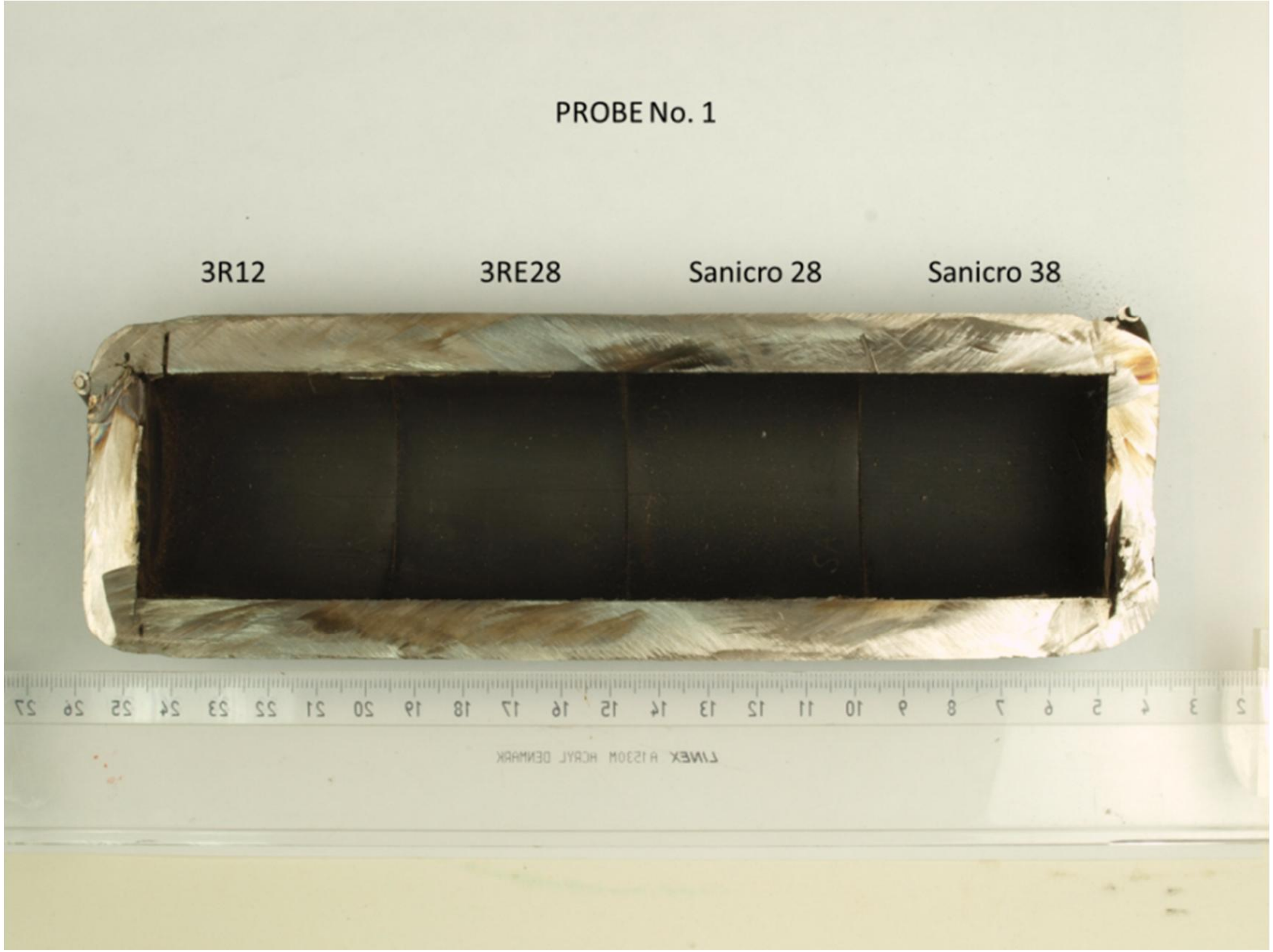
Test No.	Test materials	Test duration, hours		Effective temperature
		Total	Effective[A)]	
1	3R12(AISI 304L), 3RE28(AISI 310S), Sanicro28, Sanicro38	1000	906 (pressure over 9 bar)	ca. 440°C
2	3R12(AISI 304L), 3XRE28, HR11N, Sanicro67,	1000	744 (pressure over 8 bar)	ca. 440°C
3	3R12(AISI 304L), HR11N, Sanicro38, Super625	1000	750 (pressure over 7 bar)	ca. 430°C
4	3R12(AISI 304L), carbon steel (P265GH), Sanicro67, Super625	2700	2154 (pressure over 9 bar)	ca. 440°C
5	3R12(AISI 304L), Sanicro28, HR11N, Sanicro38	2630	2157 (pressure over 9 bar)	ca. 440°C

[A)]Used in corrosion rate calculations

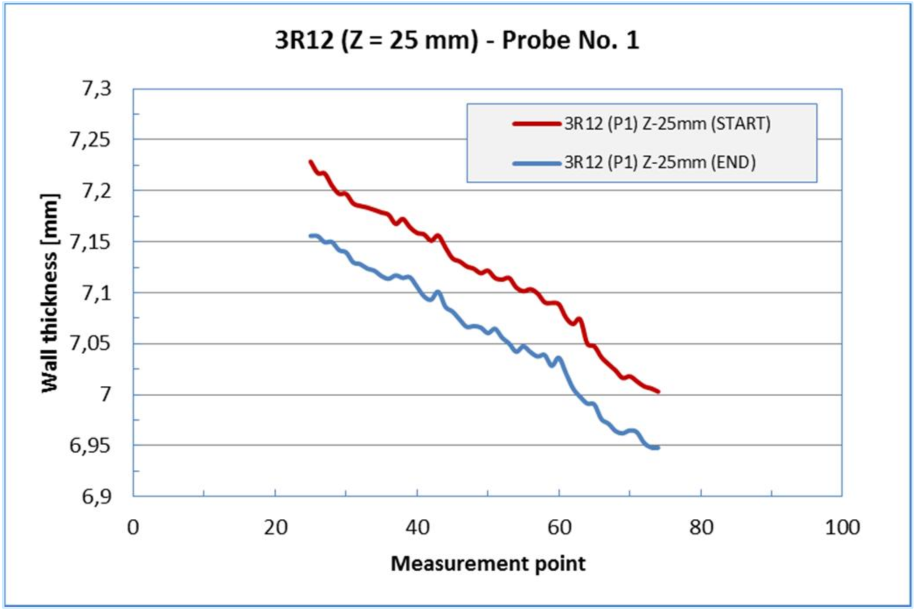
Results – Probe test No. 1

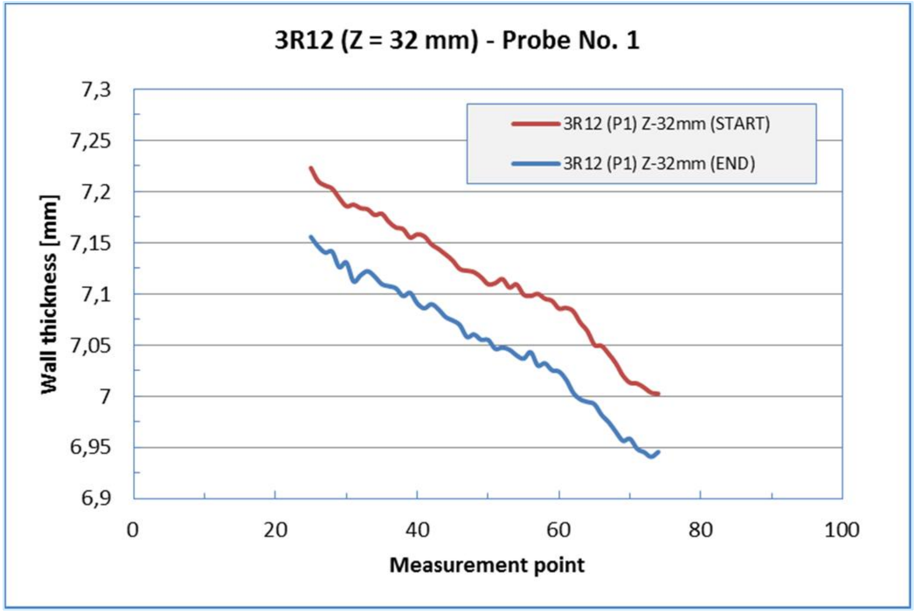
Probe No.1 after the test

Probe No.1 after the test

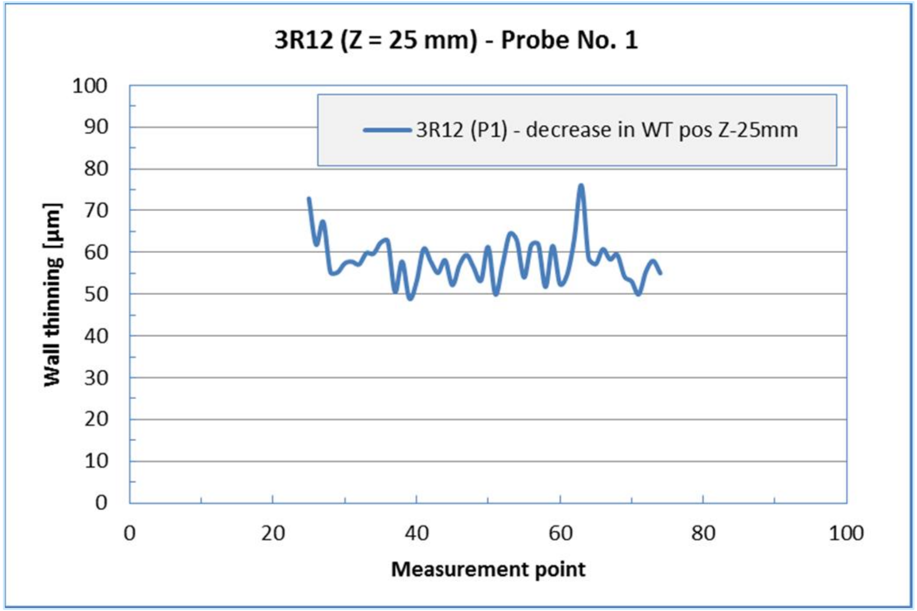


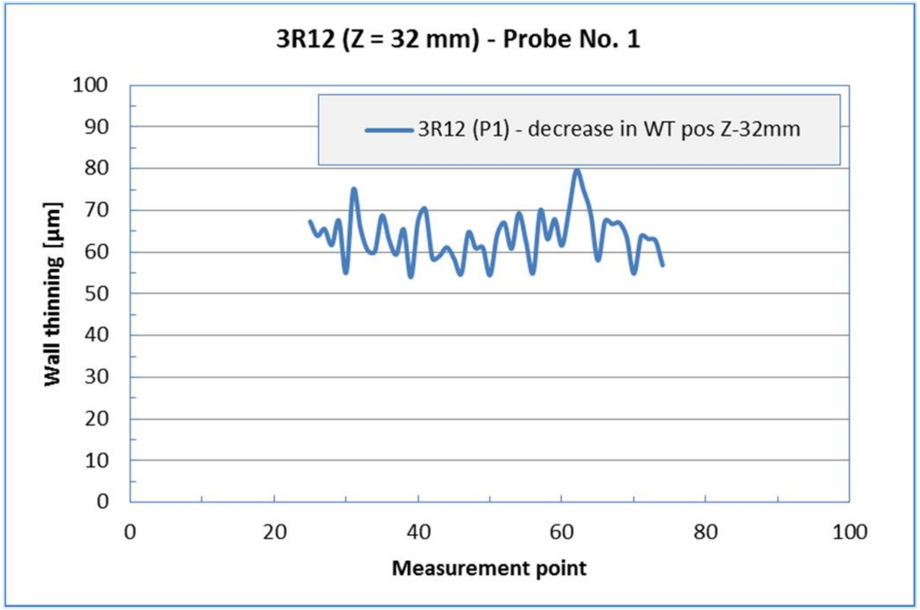
Results – 3R12 (304L)



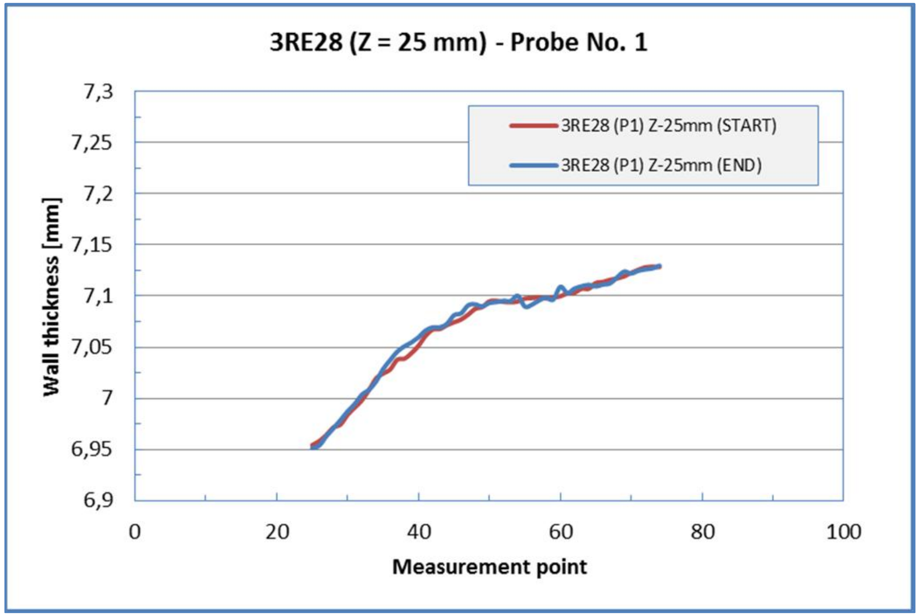


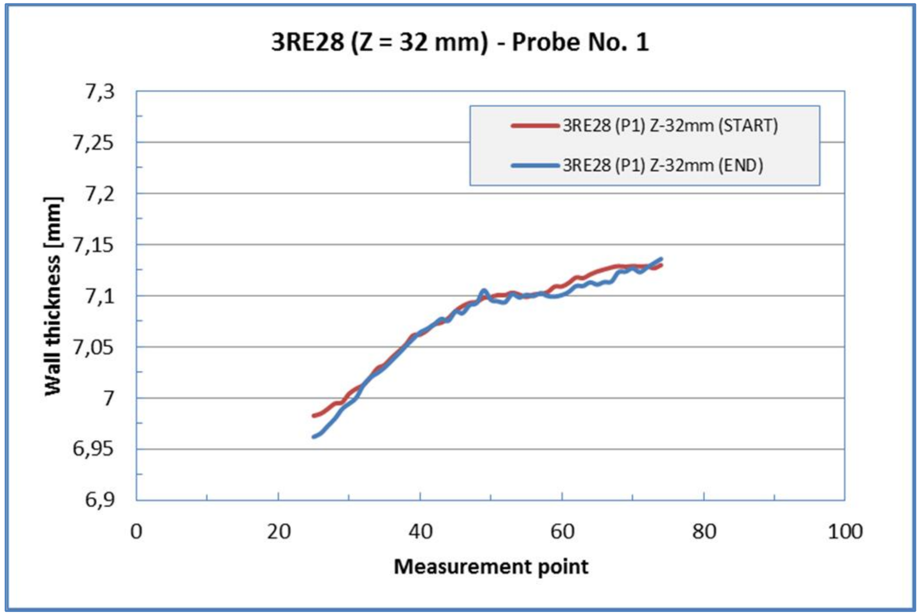
Results – 3R12 (304L)



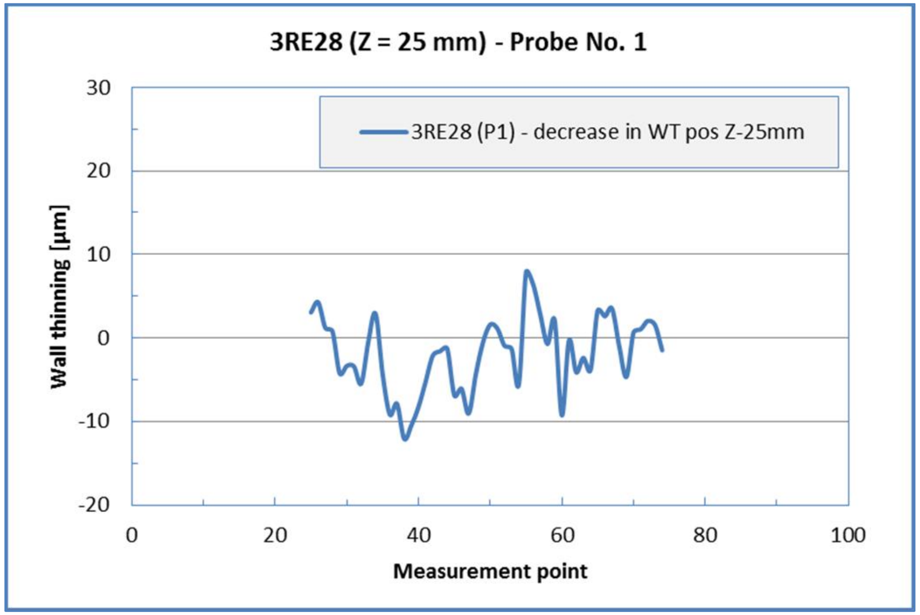


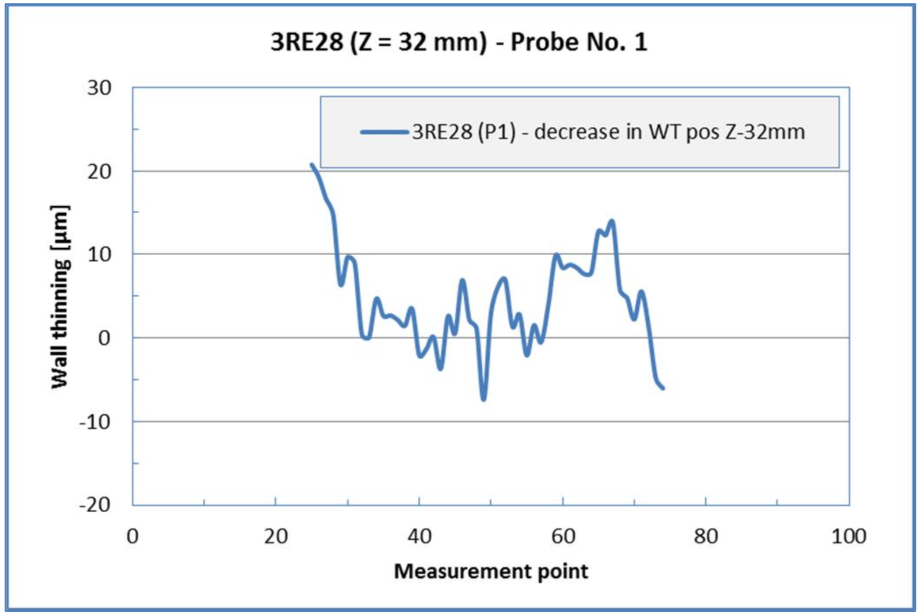
Results – 3RE28



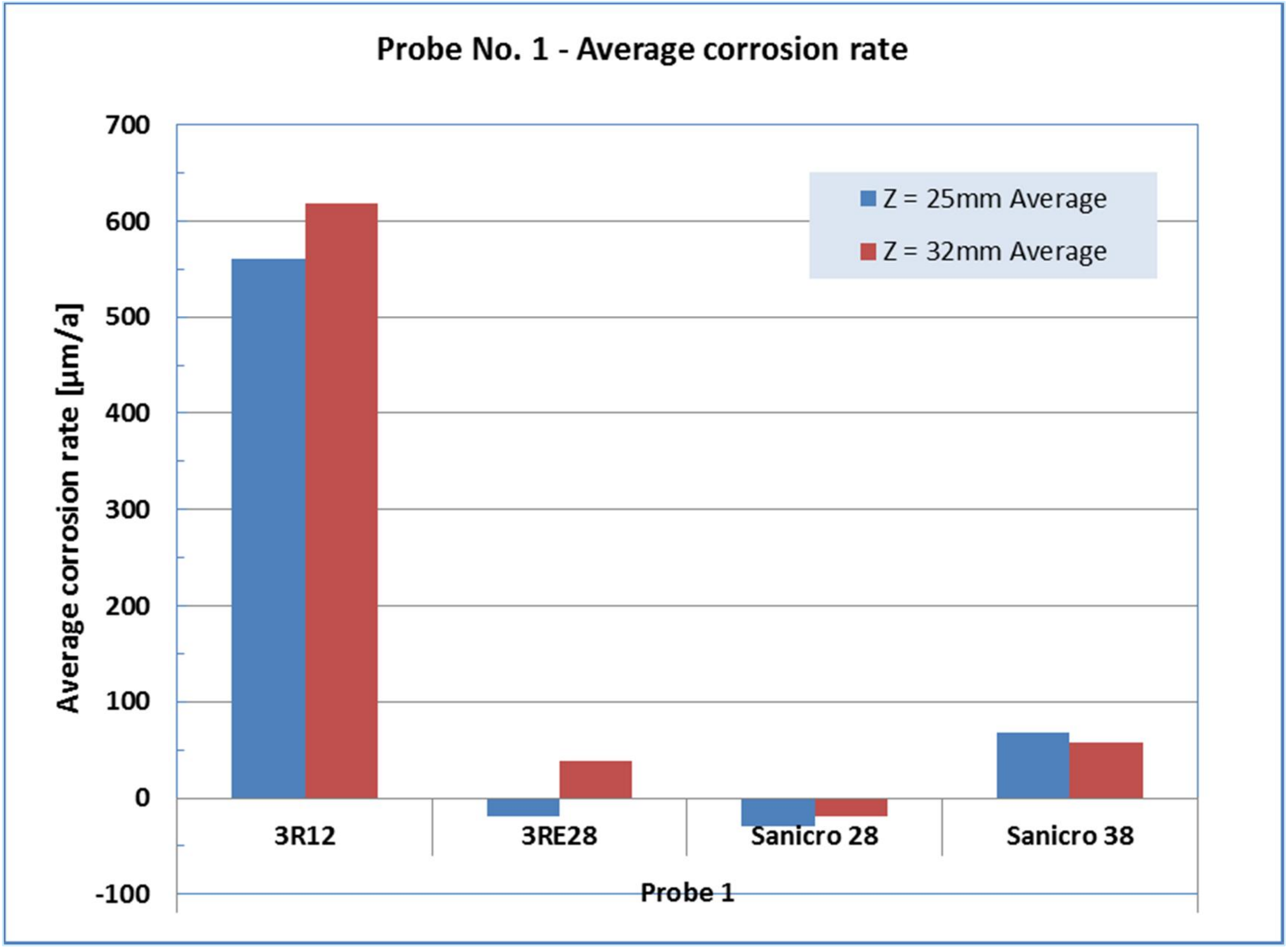


Results – 3RE28

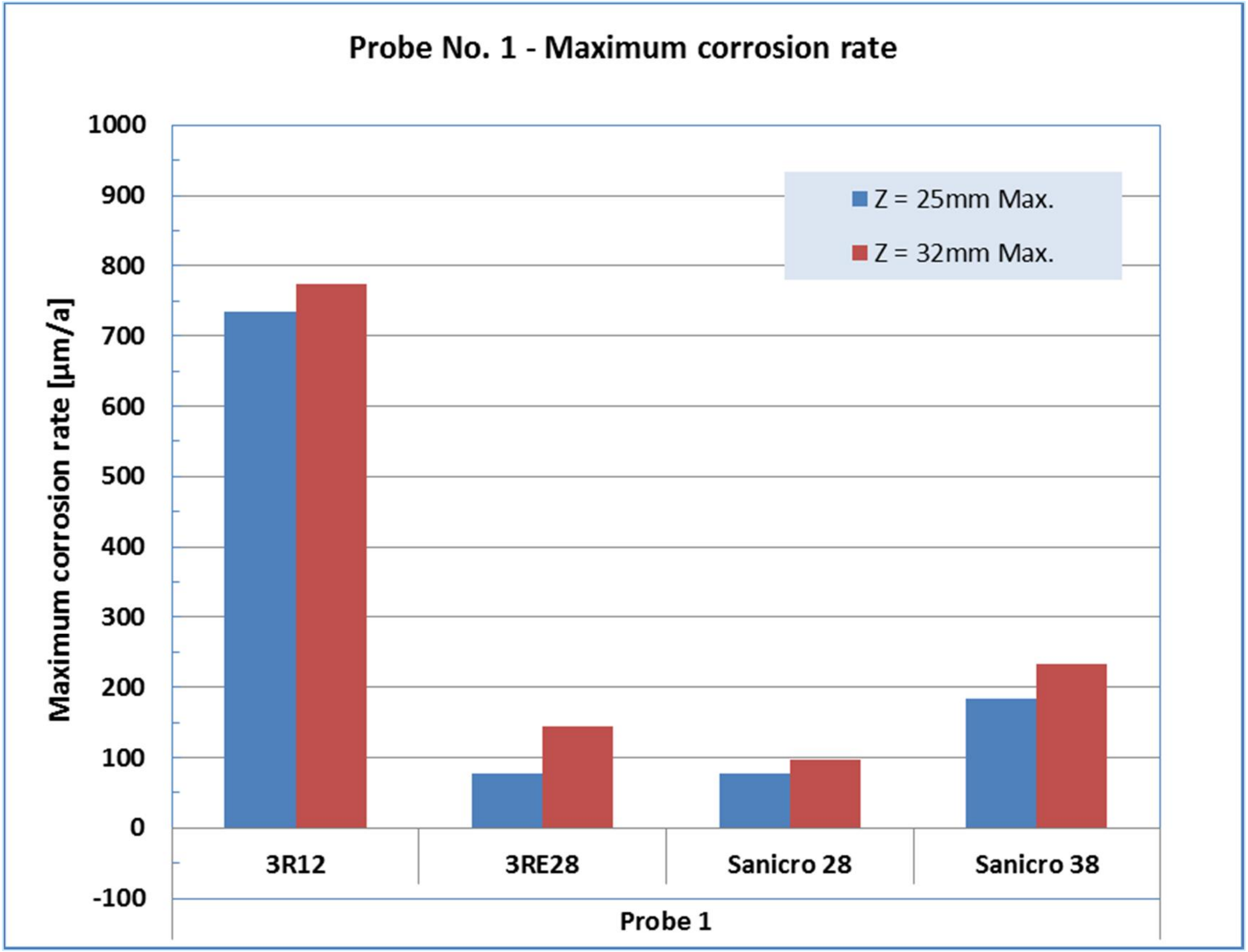




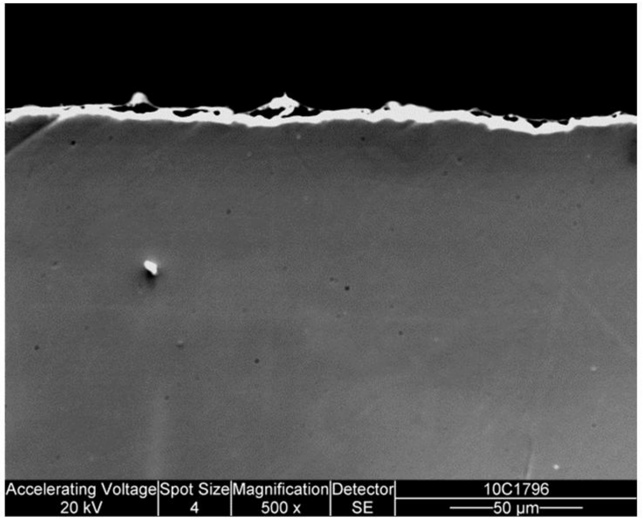
Probe test No. 1 – Average corrosion rates



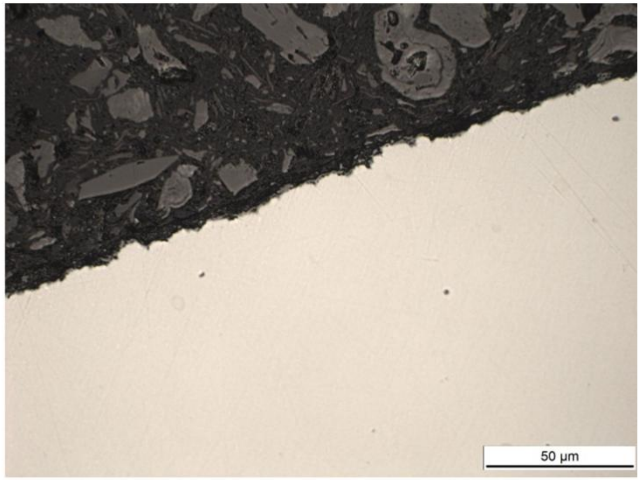
Probe test No. 1 – Maximum corrosion rates



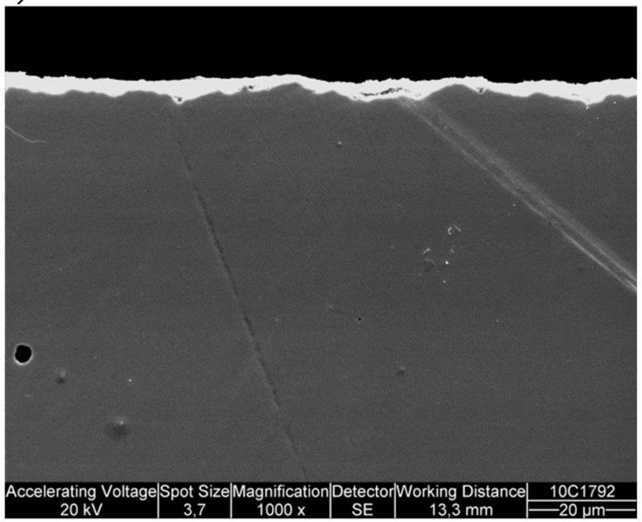
Probe test No. 1 – Metallography



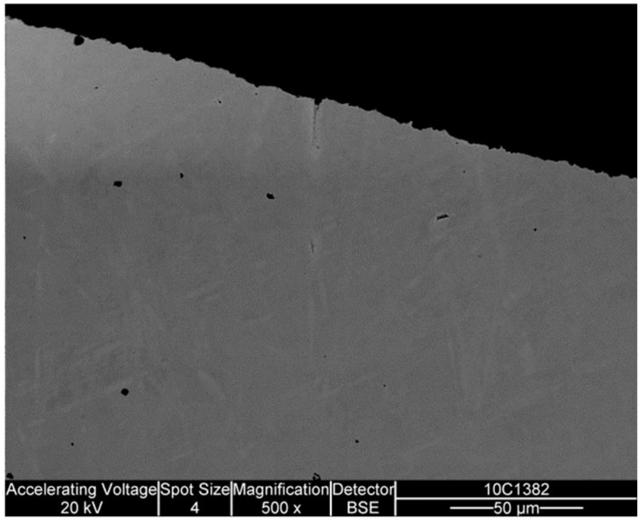
a) *3R12*



b) *3RE28*

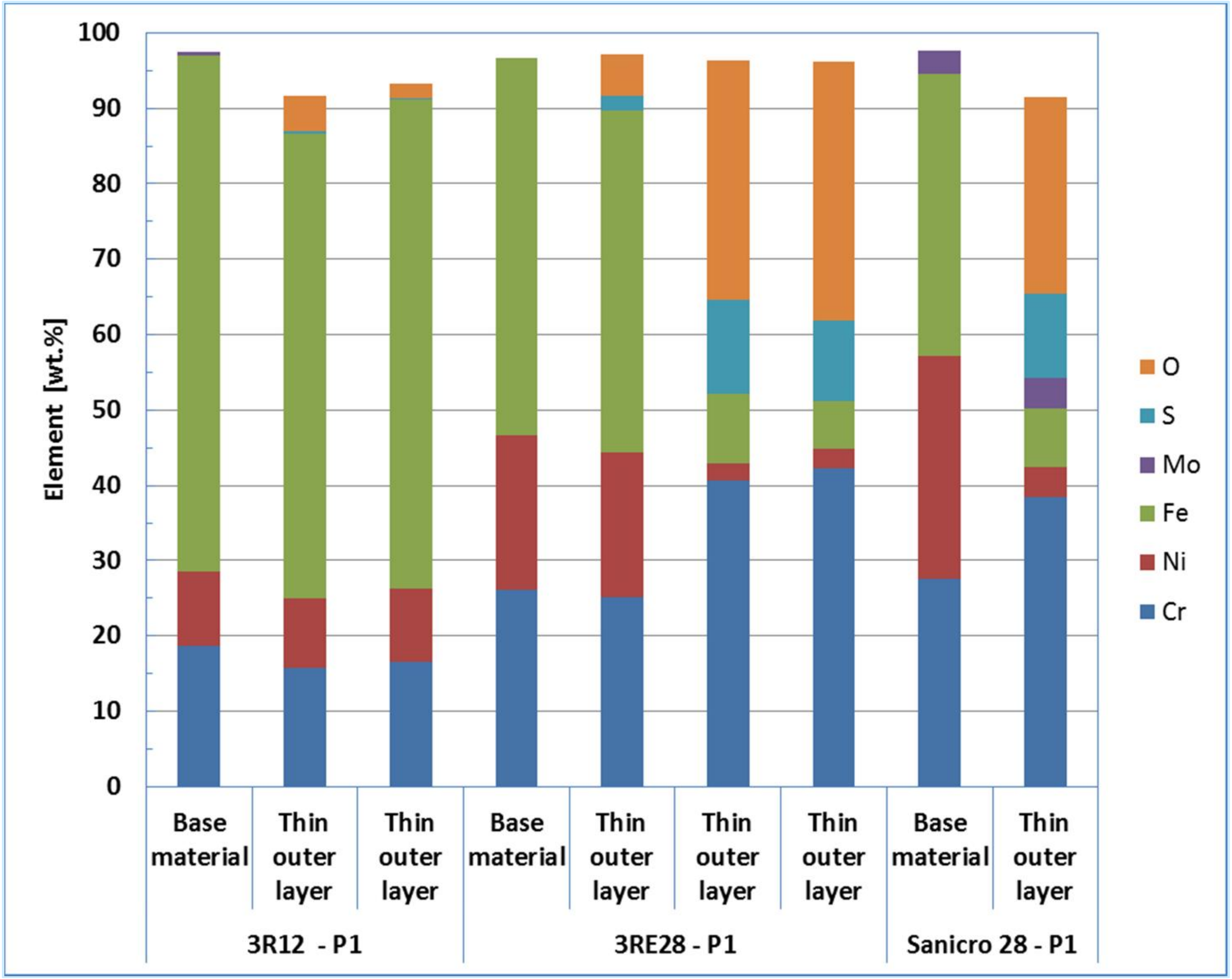


c) *Sanicro 28*



d) *Sanicro 38*

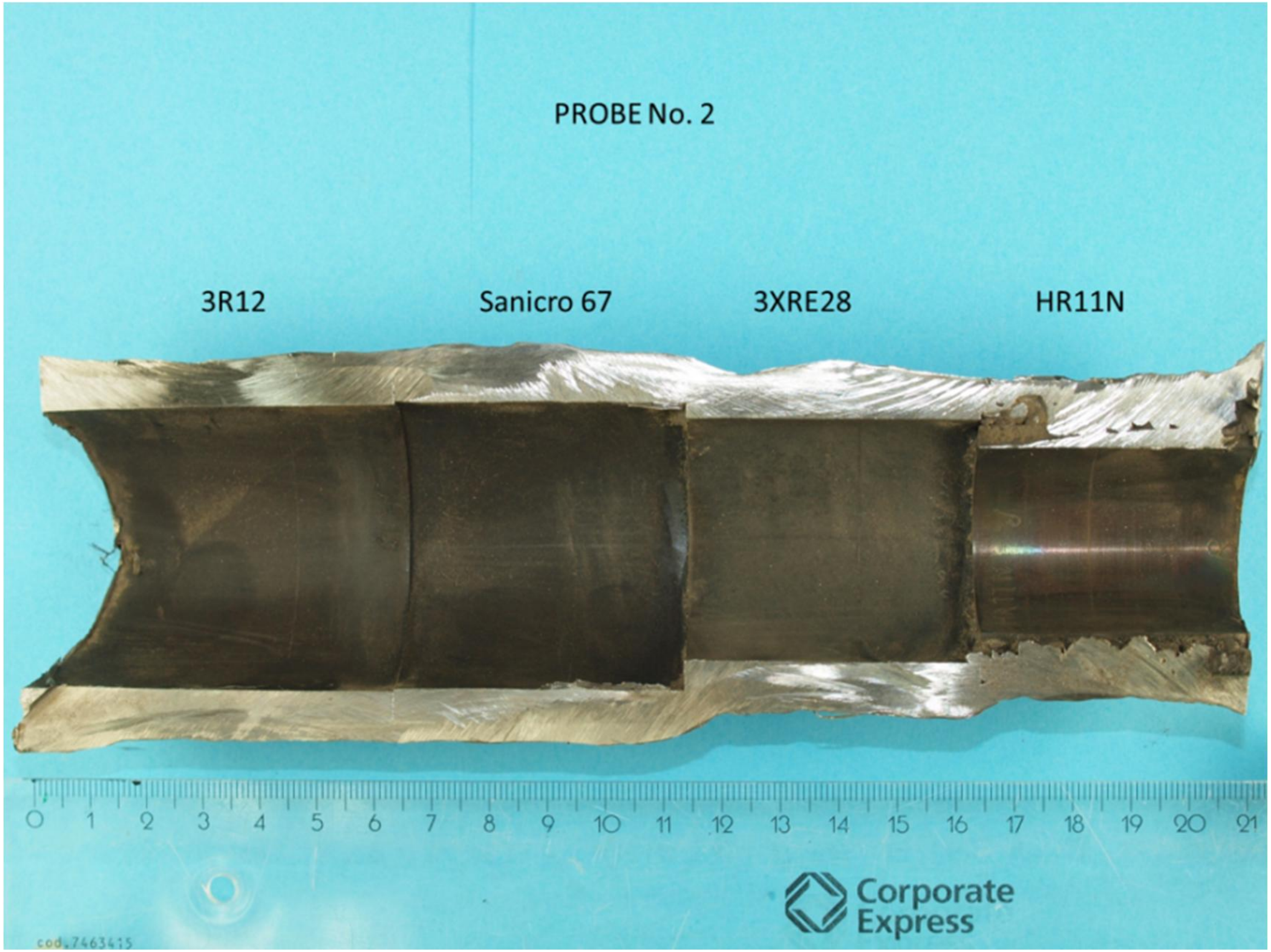
Probe test No. 1 – EDS analysis



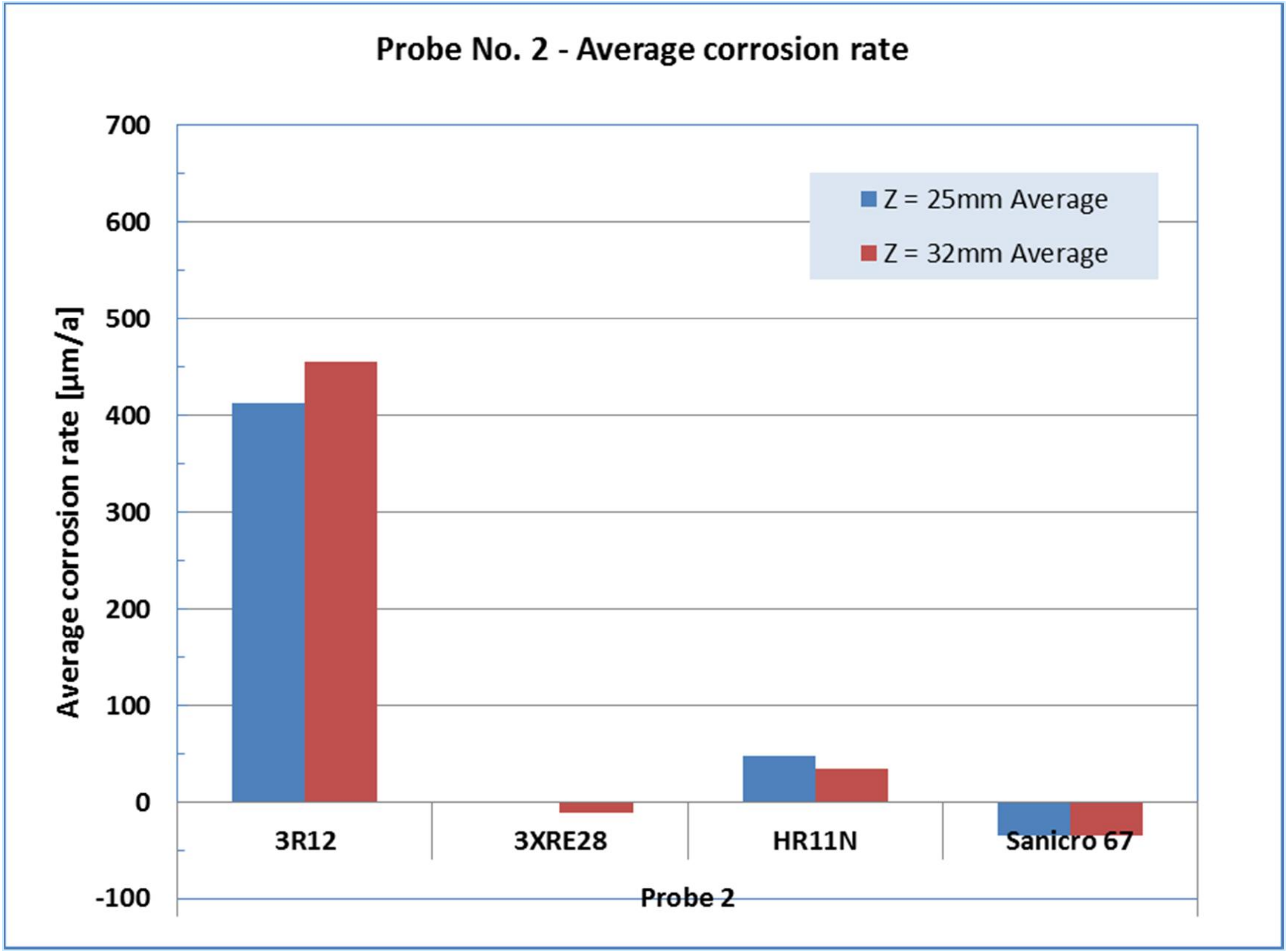
Results – Probe test No. 2

Probe No. 2 after the test

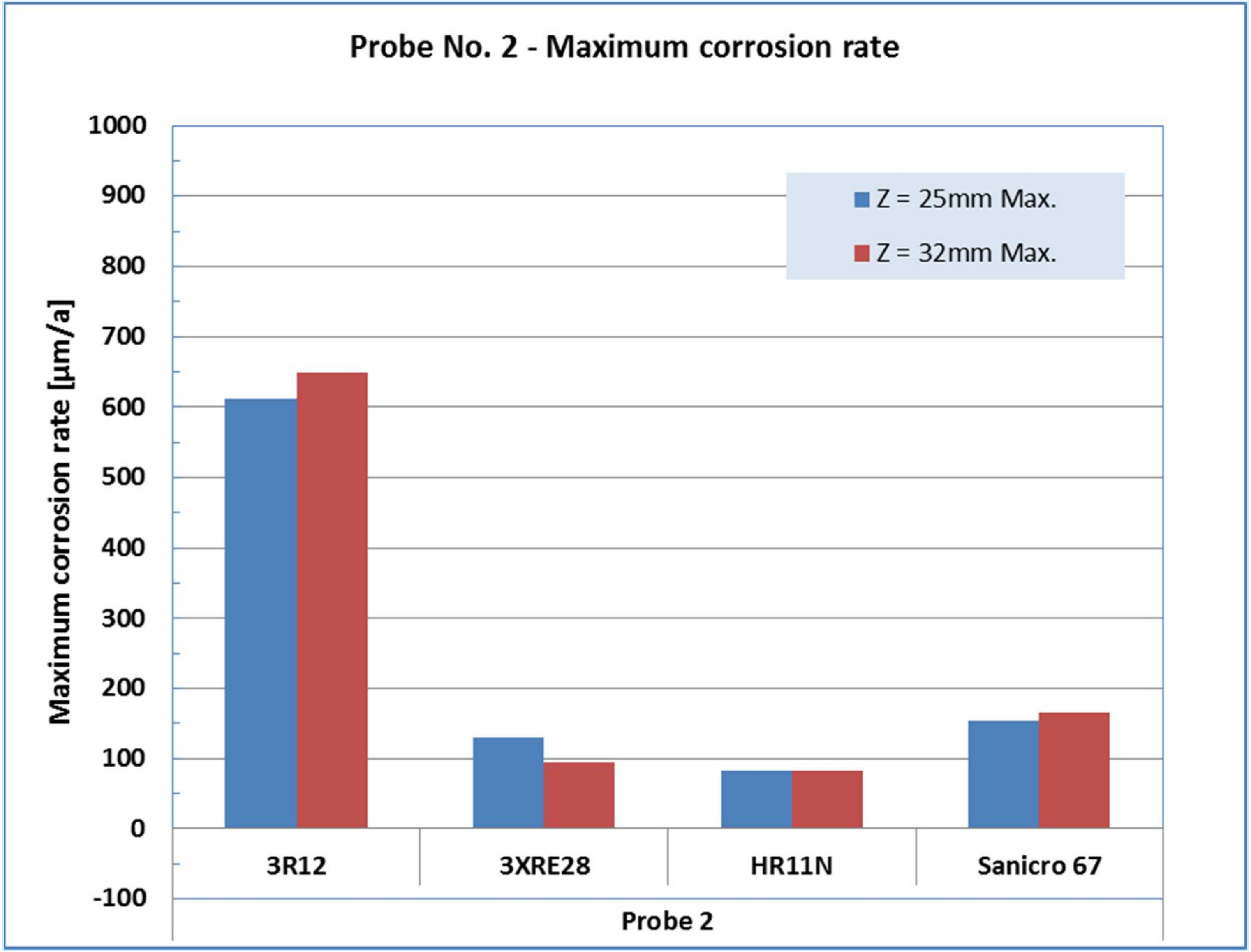
Probe No. 2 after the test



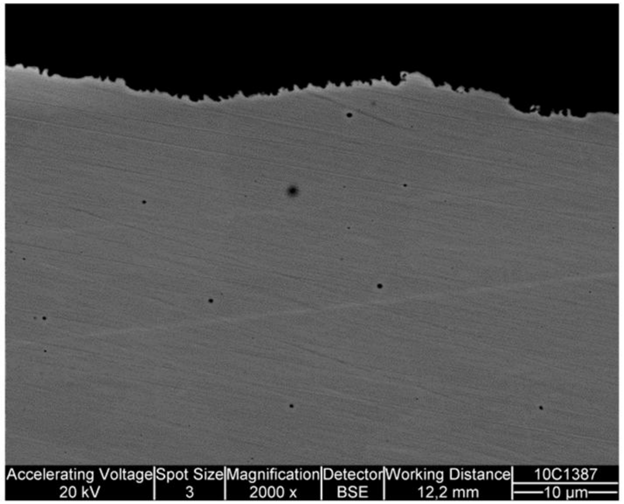
Probe test No. 2 – Average corrosion rates



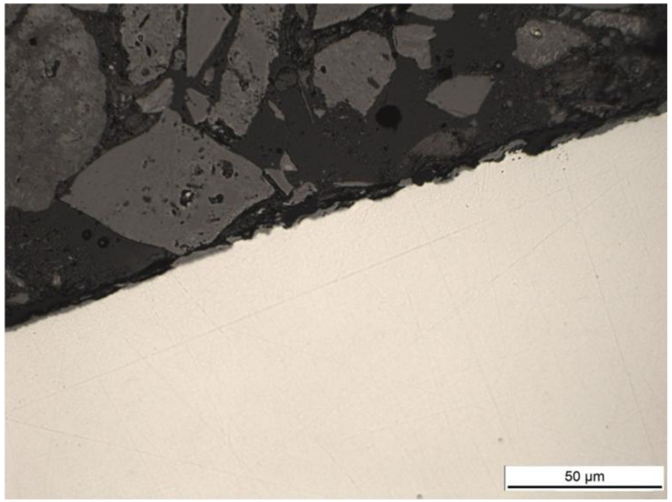
Probe test No. 2 – Maximum corrosion rates



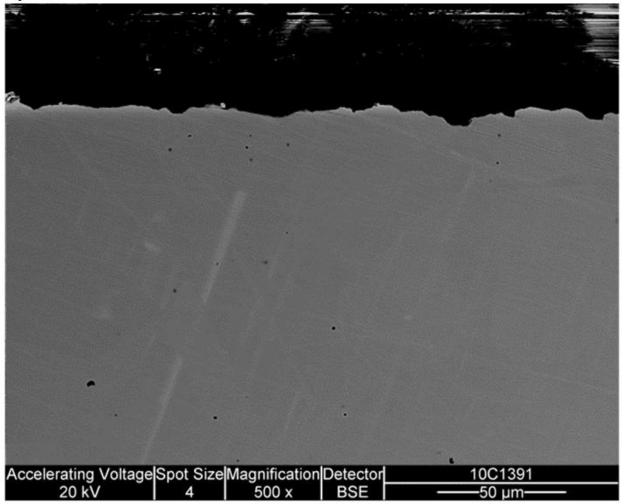
Probe test No. 2 – Metallography



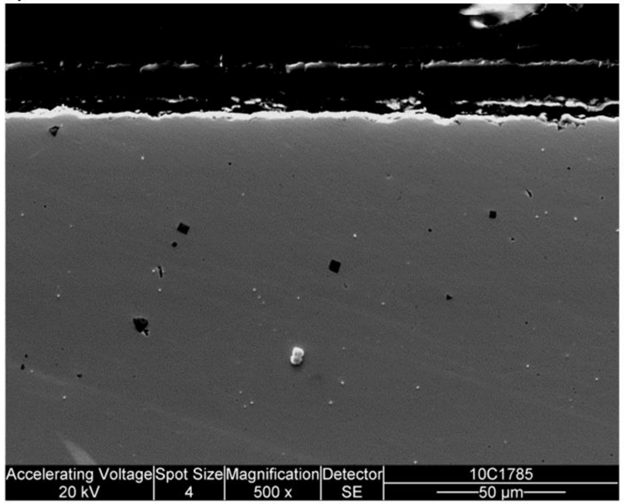
a) 3R12



b) 3XRE28

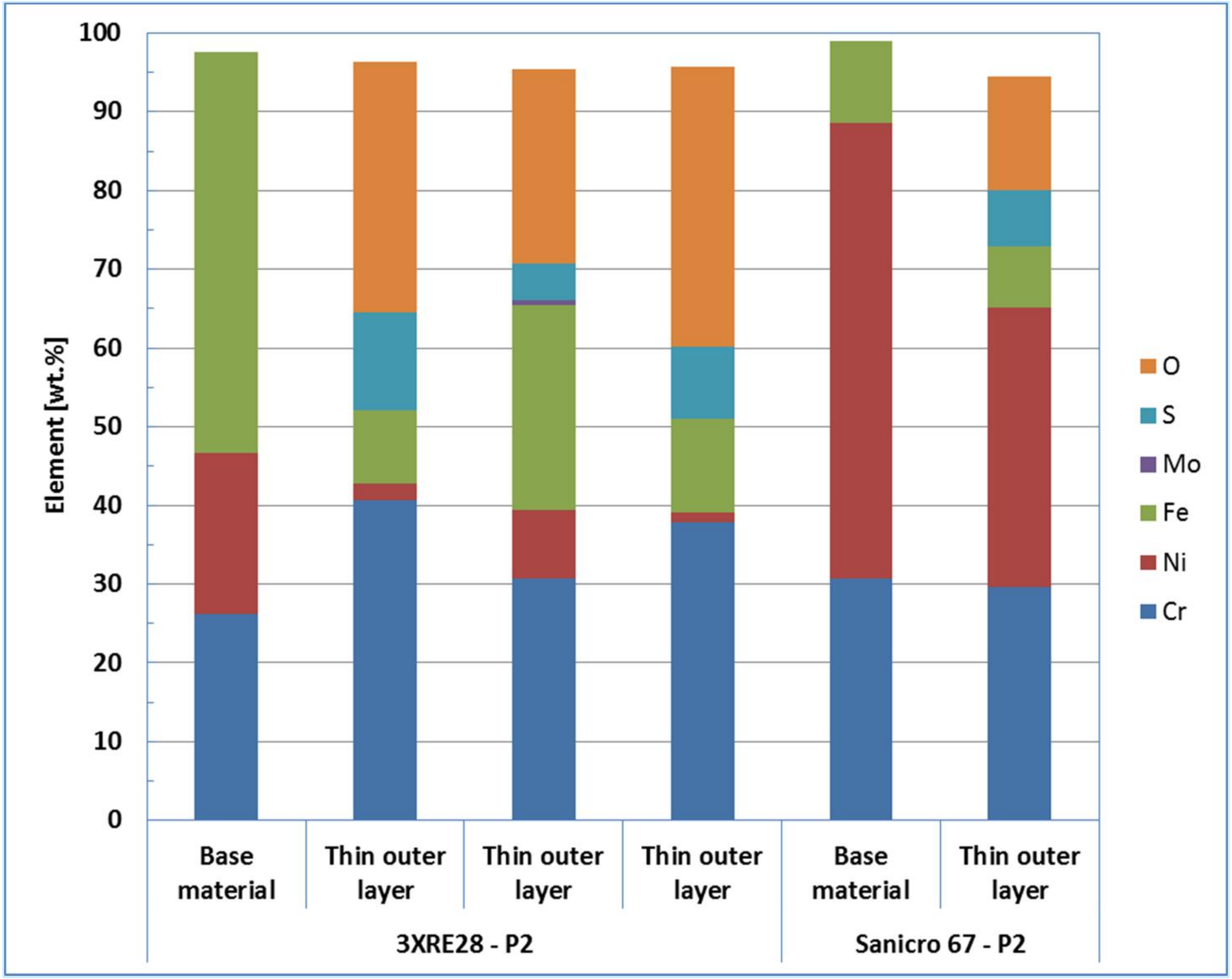


c) HR11N



d) Sanicro 67

Probe test No. 2 – EDS analysis

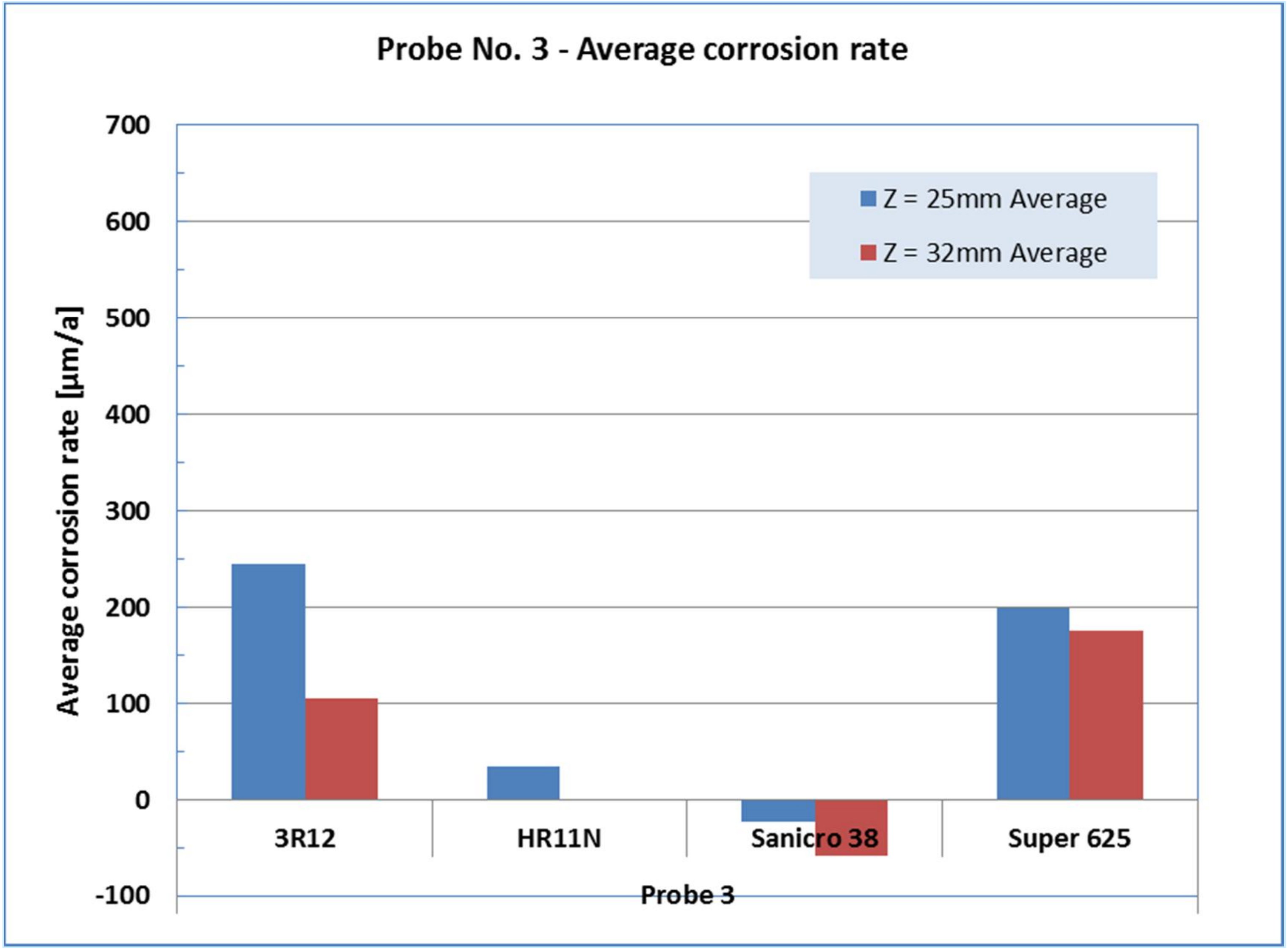


Results – Probe test No. 3

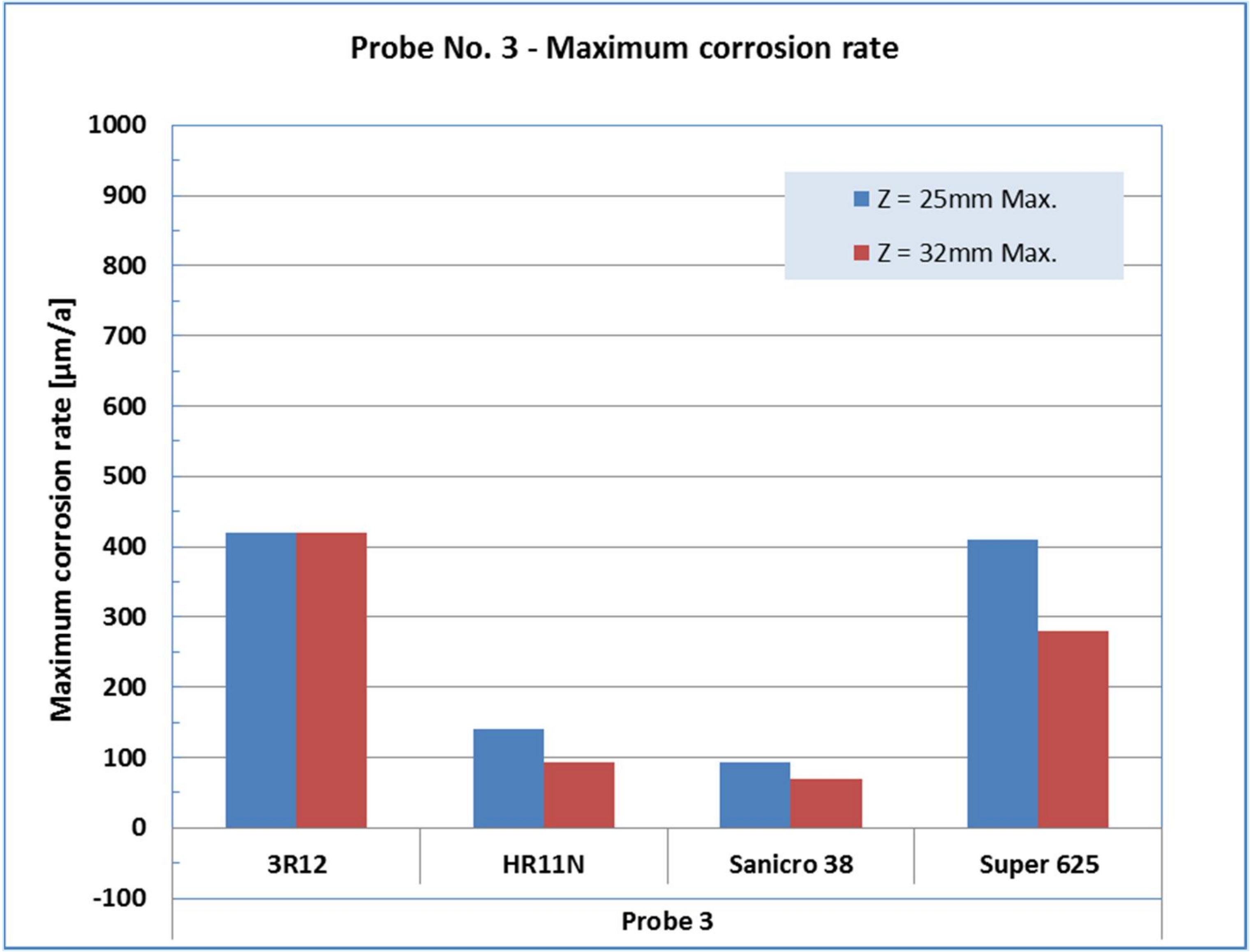
Probe No. 3 after the test

Probe No. 3 after the test

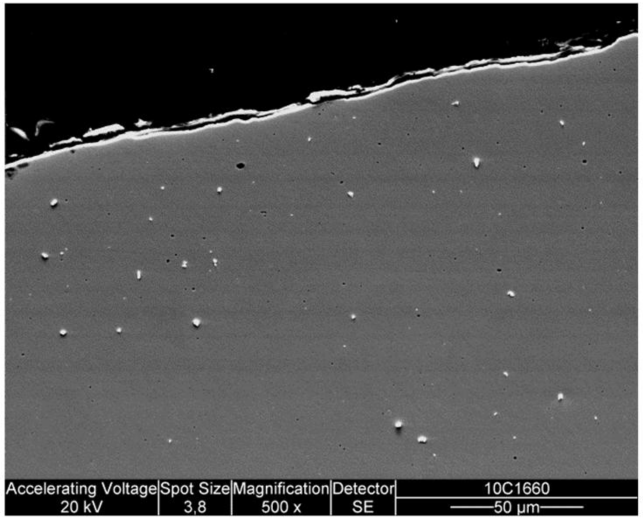
Probe test No. 3 – Average corrosion rates



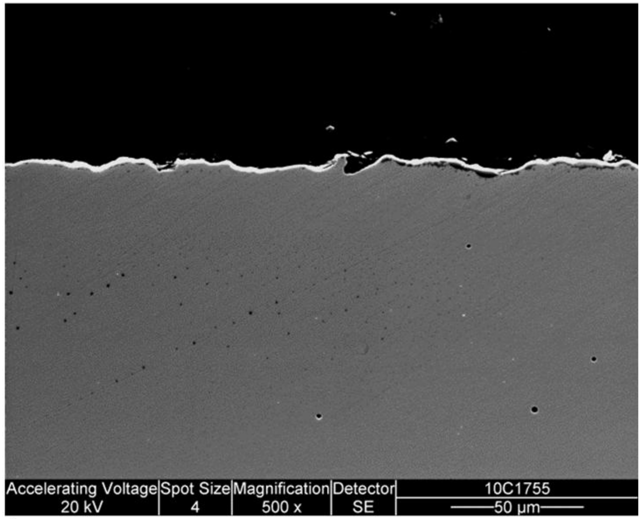
Probe test No. 3 – Maximum corrosion rates



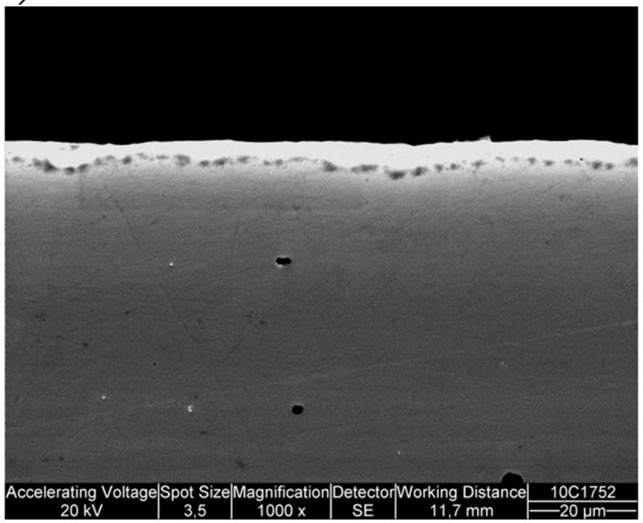
Probe test No. 3 – Metallography



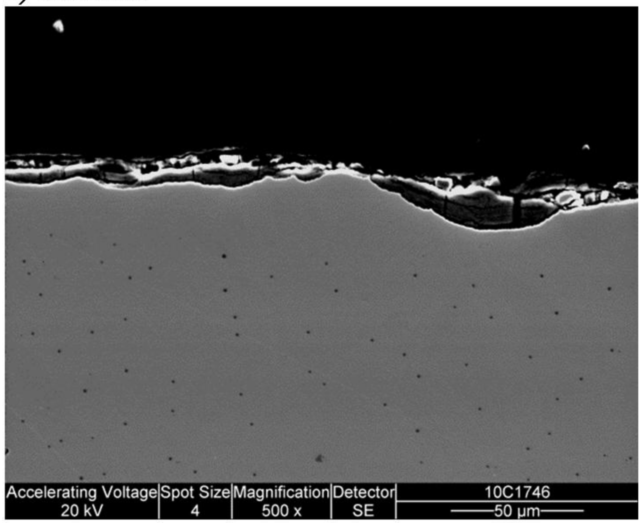
a) 3R12



b) HR11N

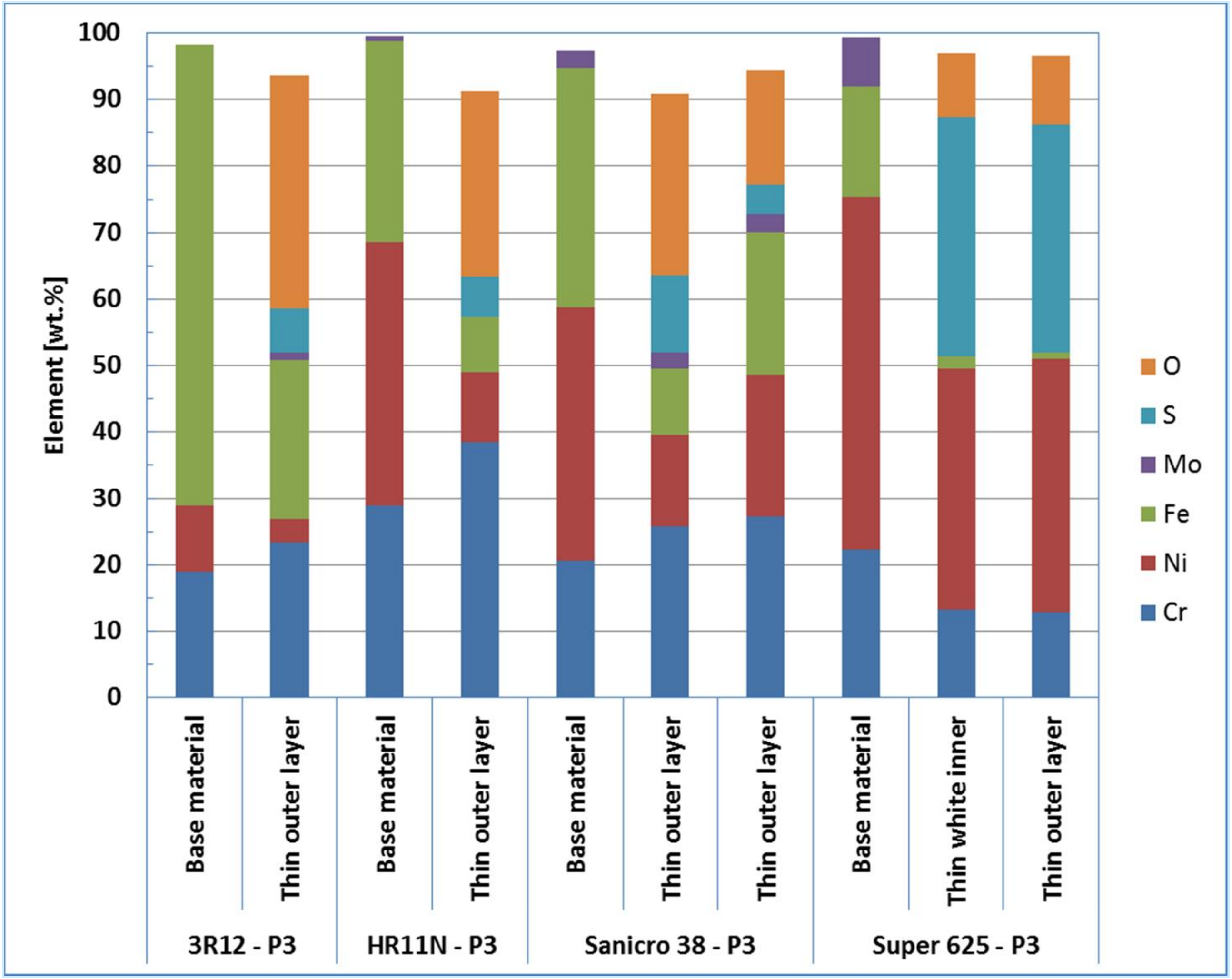


c) Sanicro 38



d) Super 625

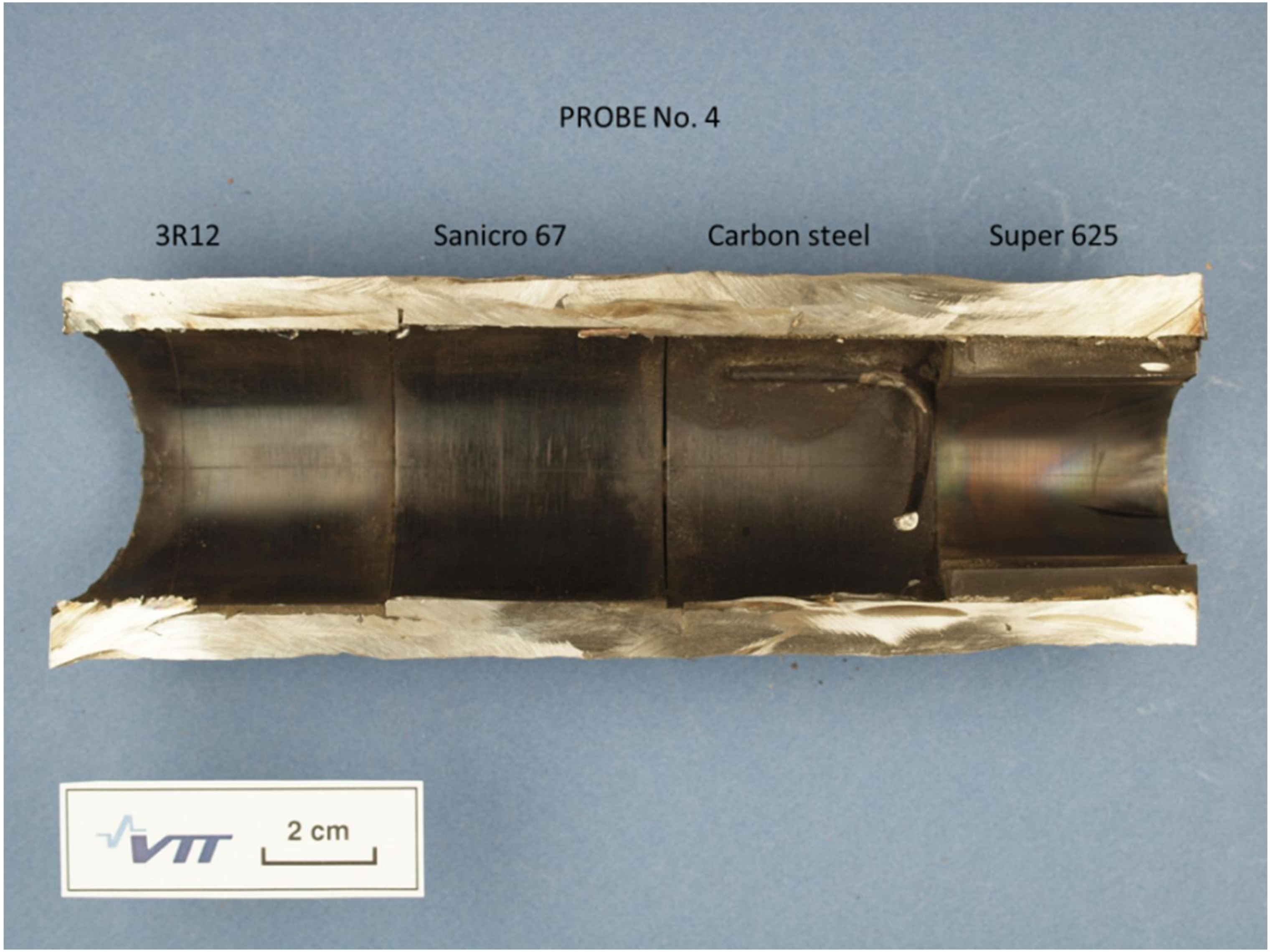
Probe test No. 3 – EDS analysis



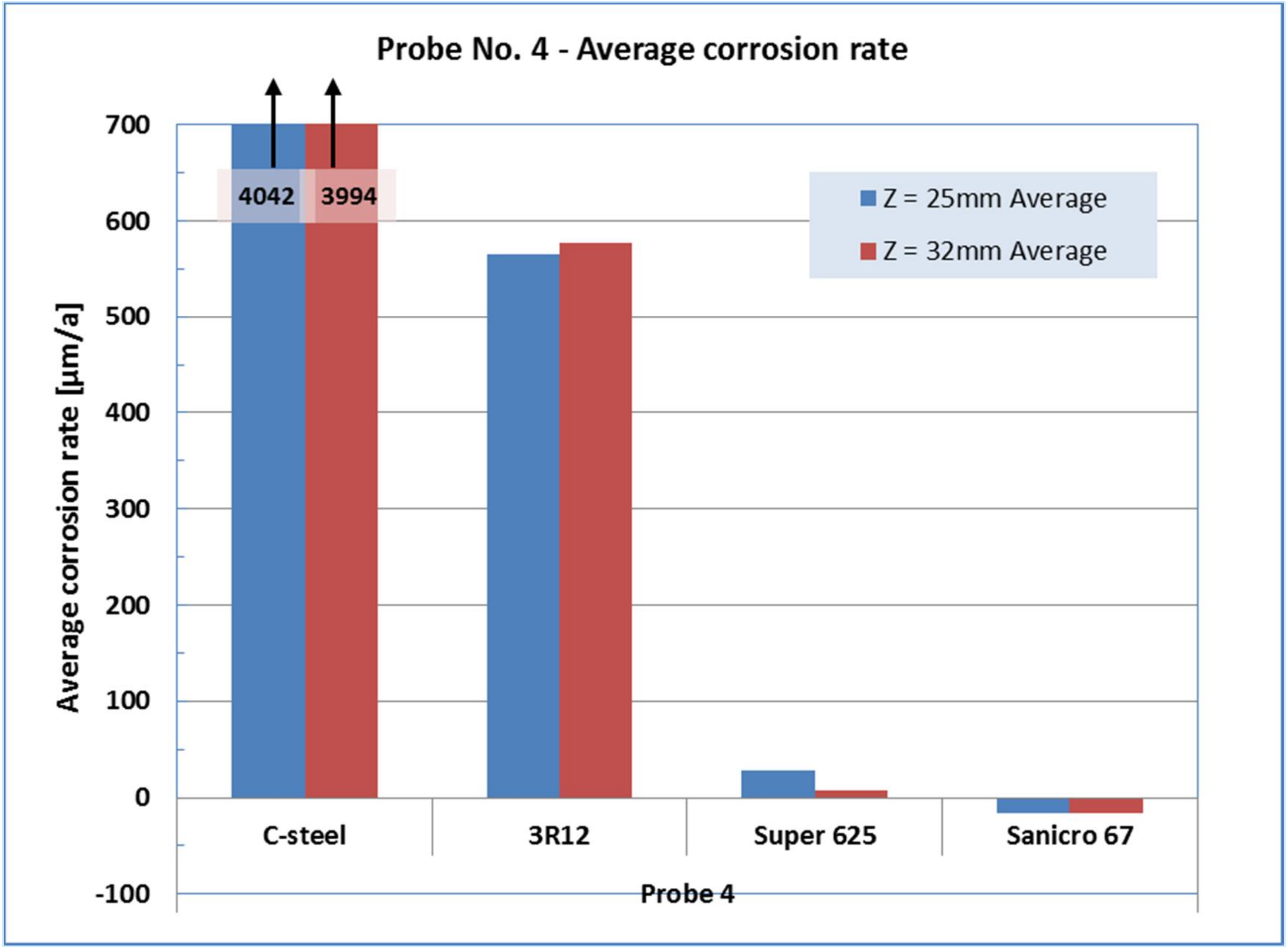
Results – Probe test No. 4

Probe No. 4 after the test

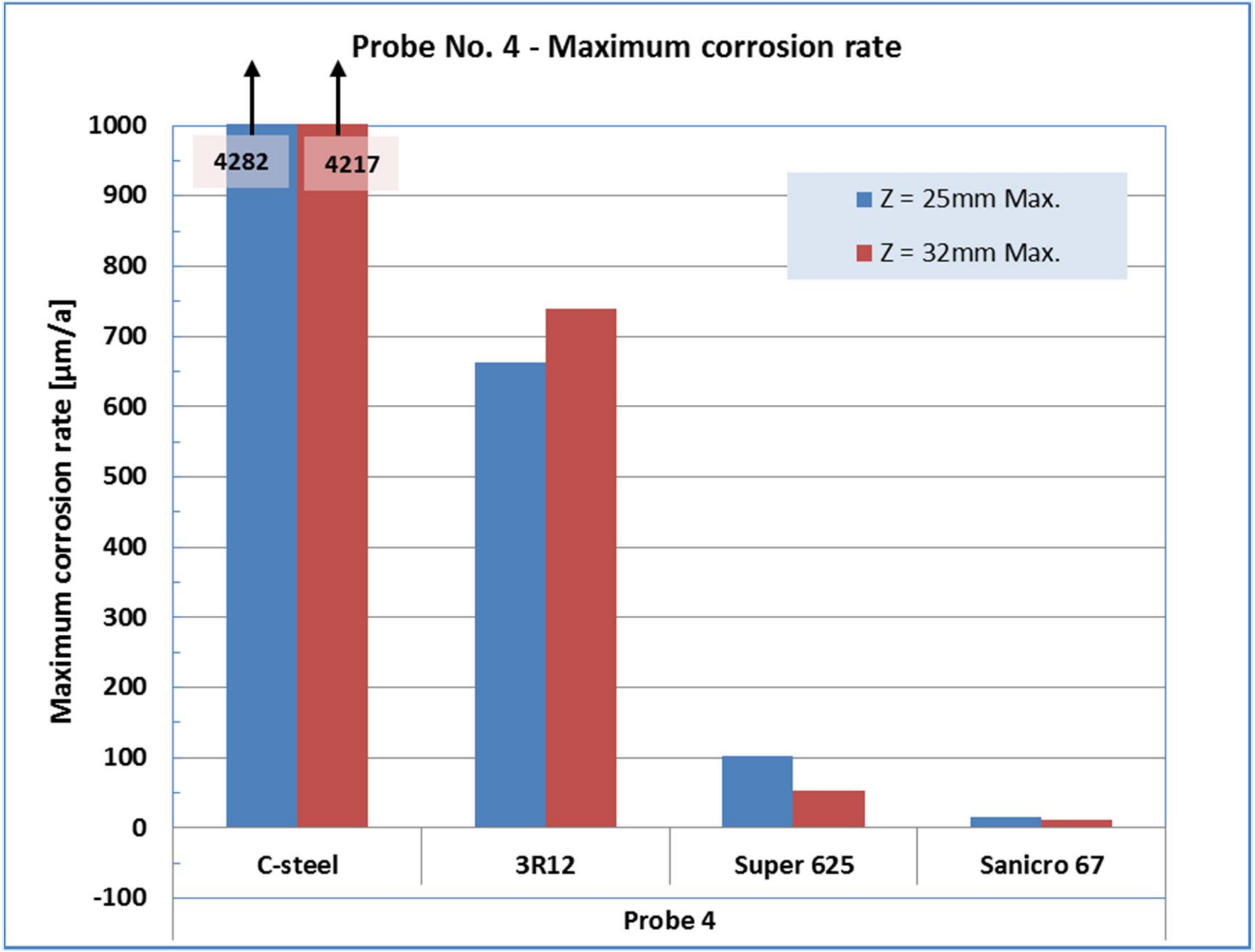
Probe No. 4 after the test



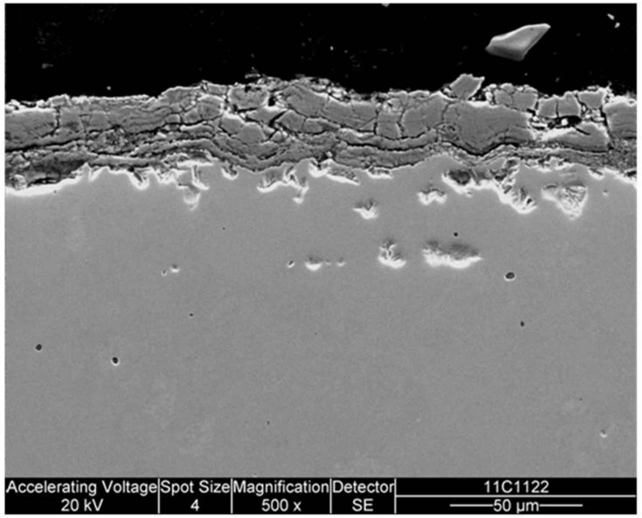
Probe test No. 4 – Average corrosion rates



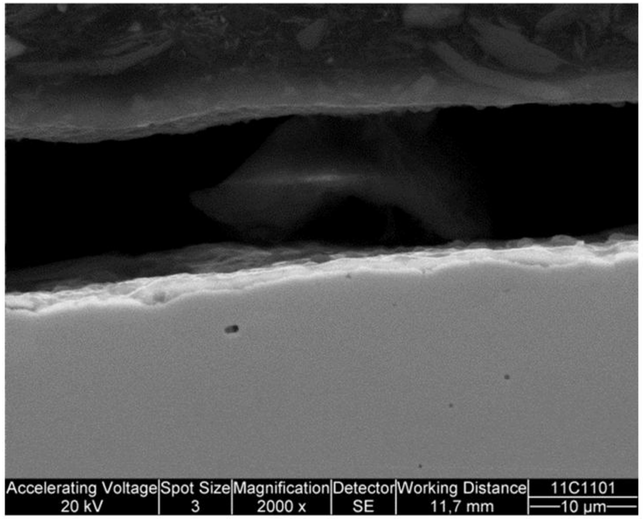
Probe test No. 4 – Maximum corrosion rates



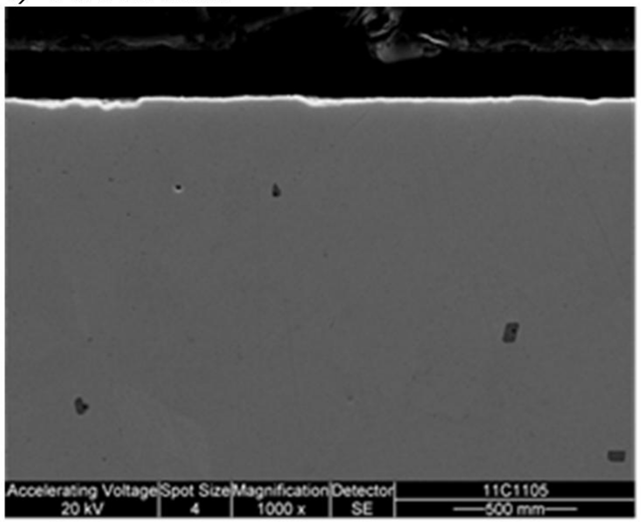
Probe test No. 4 – Metallography



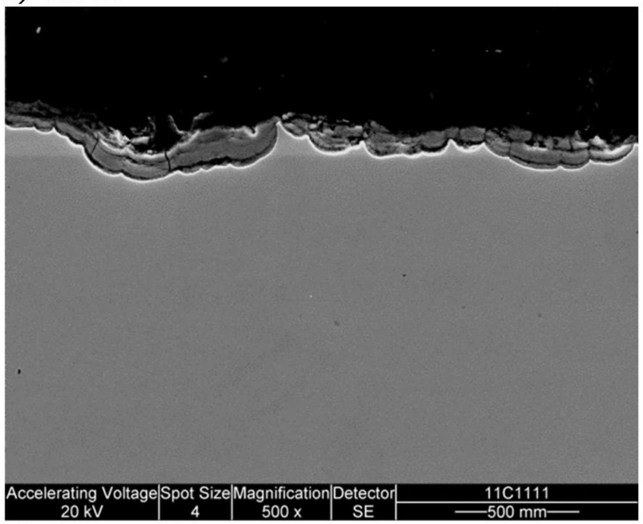
a) Carbon steel



b) 3R12

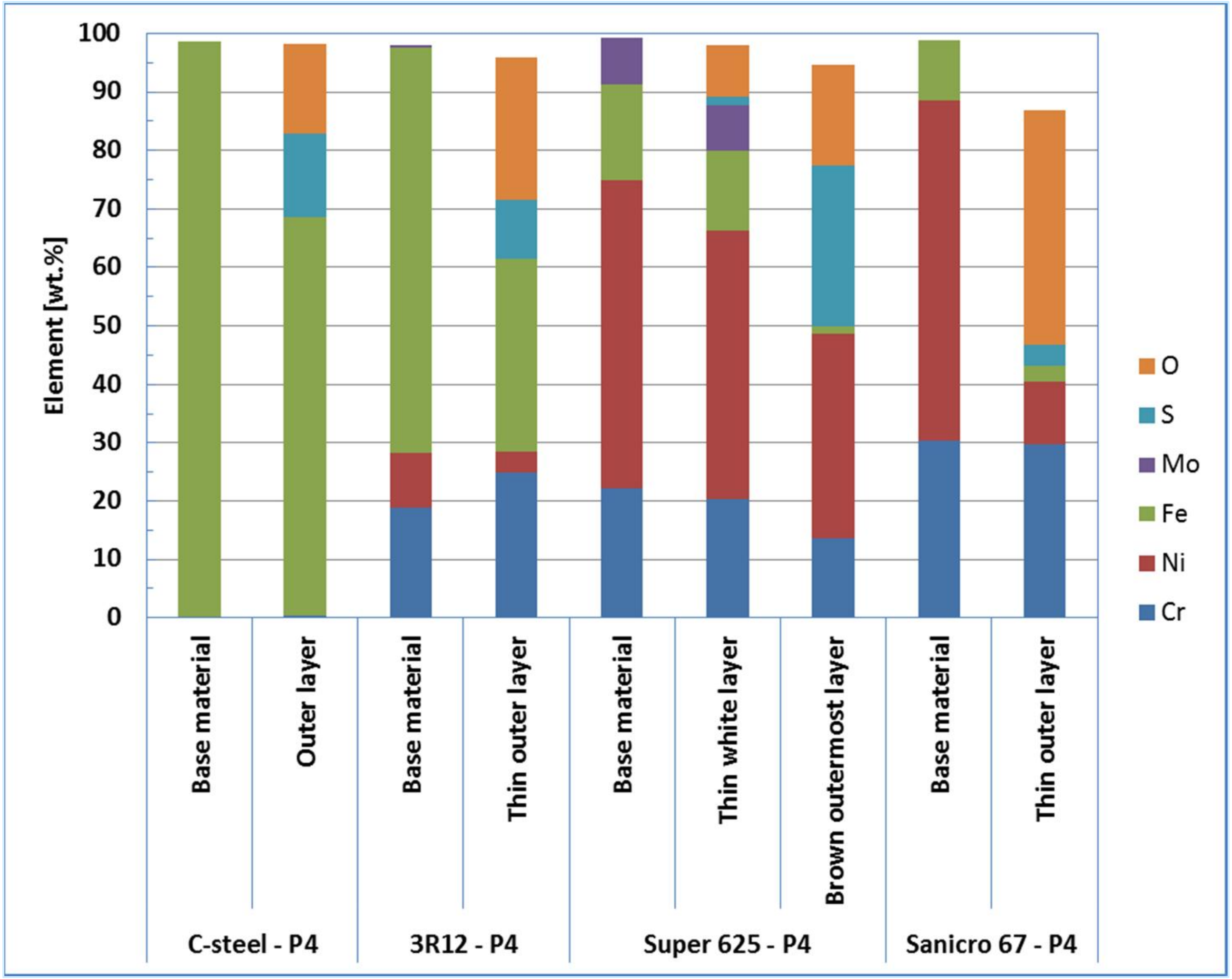


c) Sanicro 67



d) Super 625

Probe test No. 4 – EDS analysis

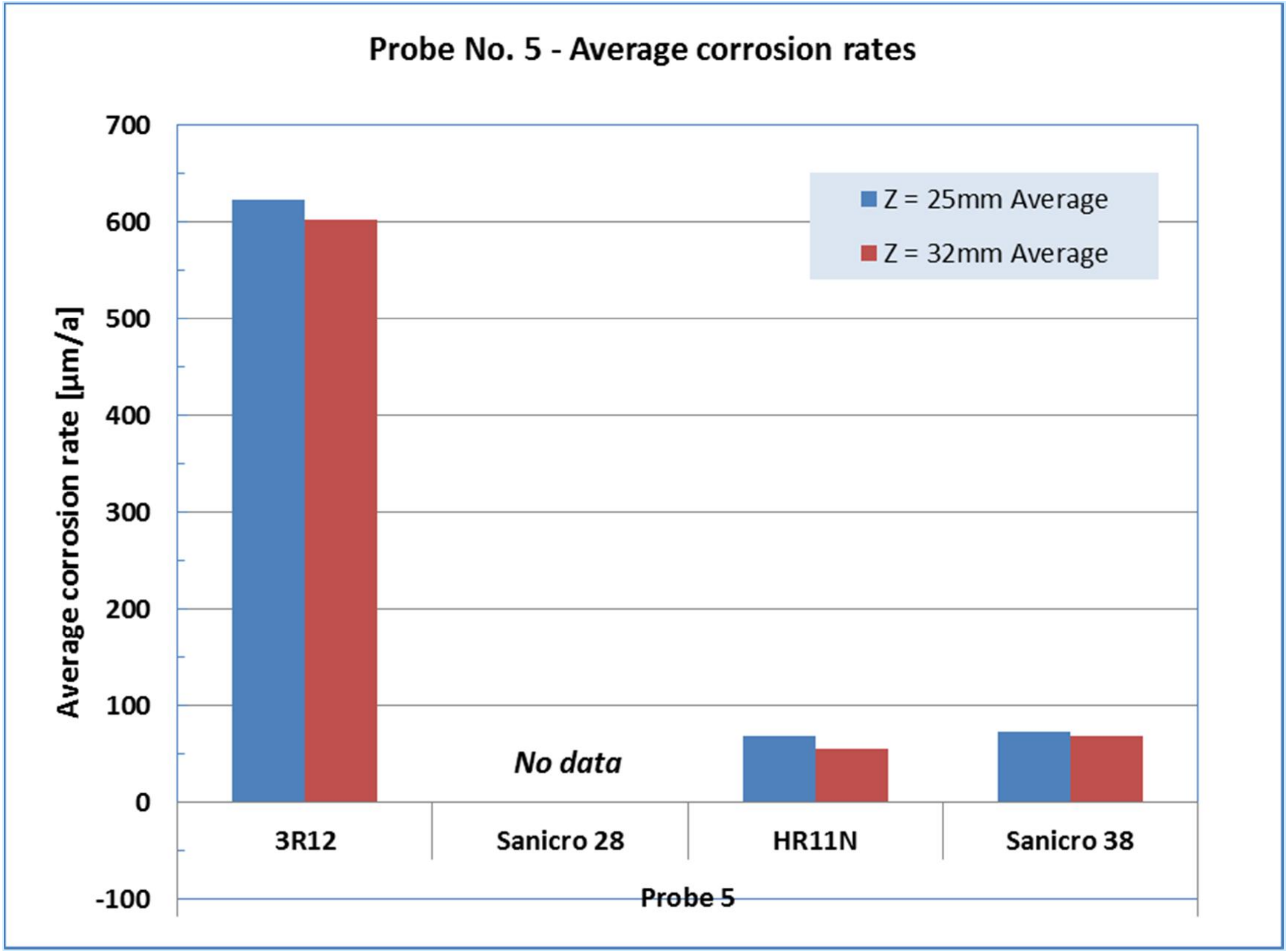


Results – Probe test No. 5

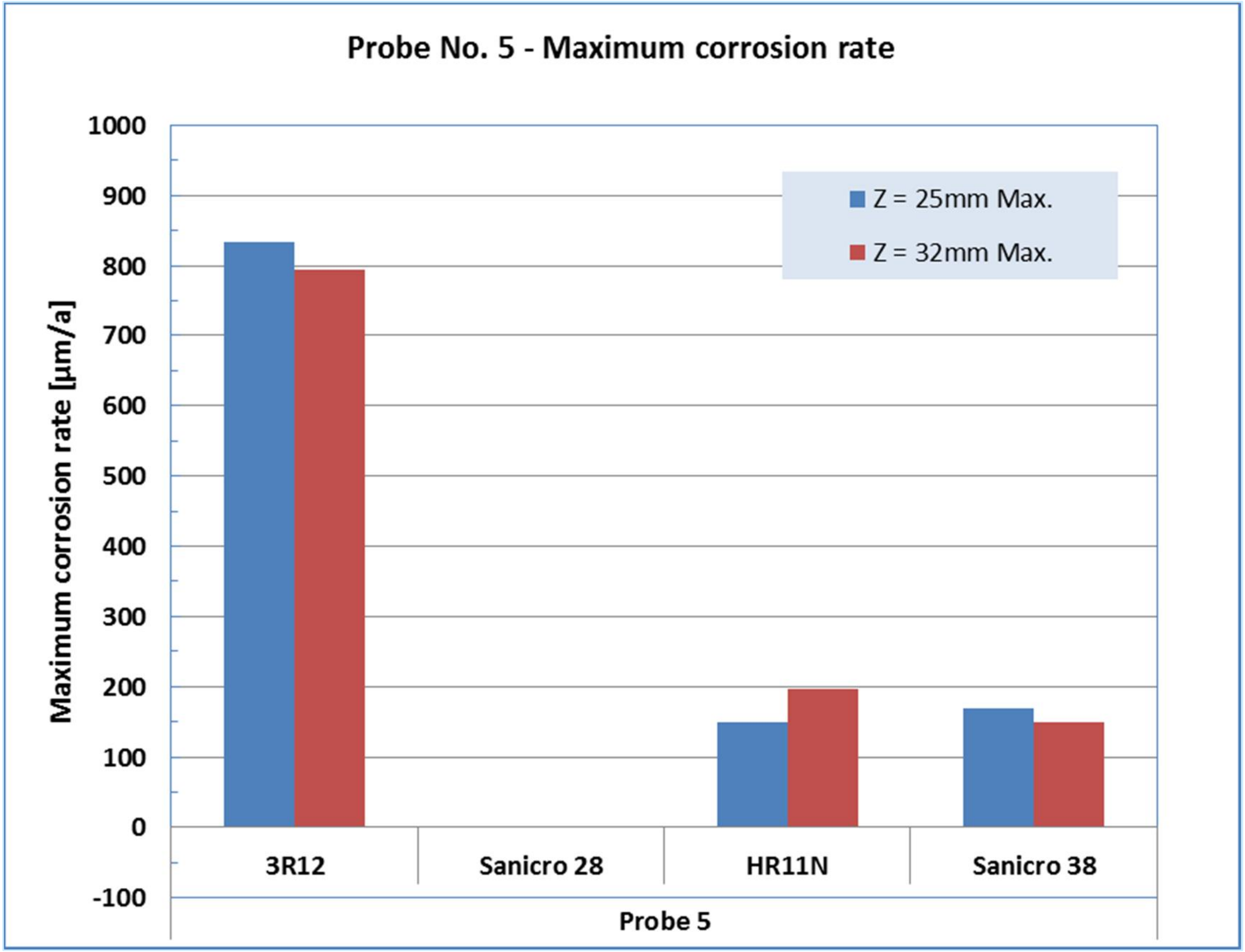
Probe No. 5 after the test

Probe No. 5 after the test

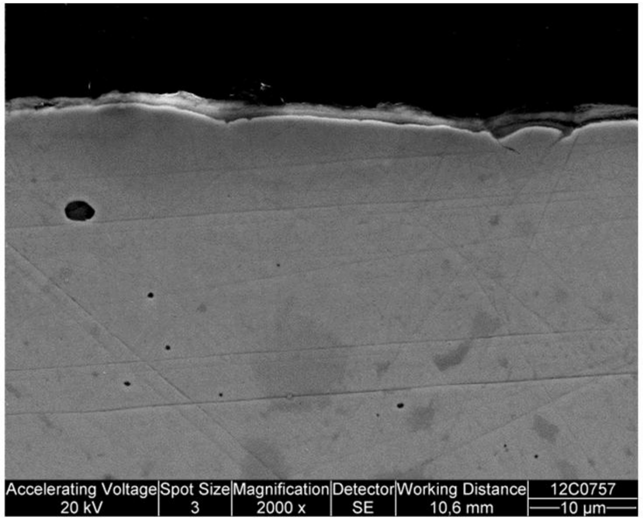
Probe test No. 5 – Average corrosion rates



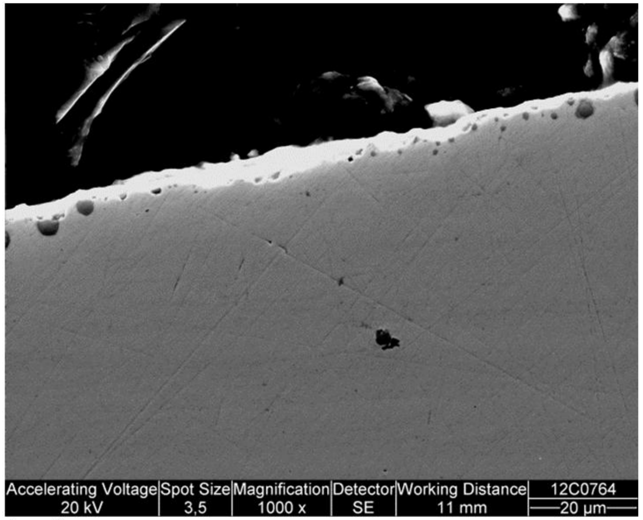
Probe test No. 5 – Maximum corrosion rates



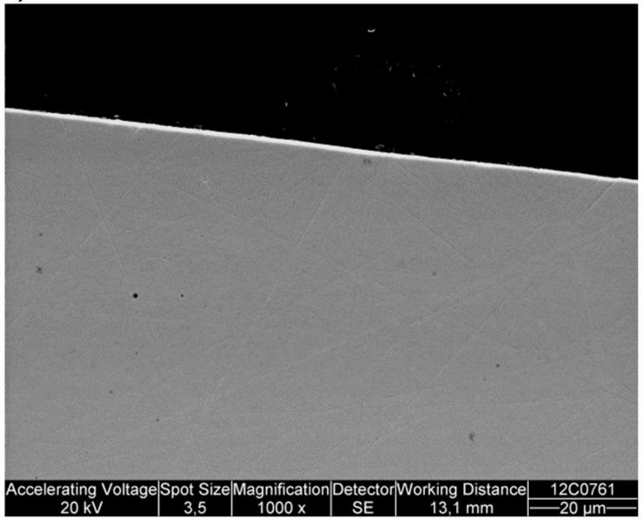
Probe test No. 5 – Metallography



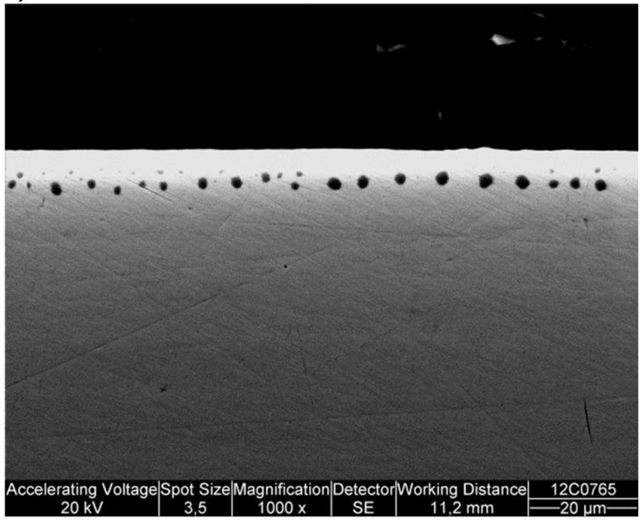
a) 3R12



b) Sanicro 28

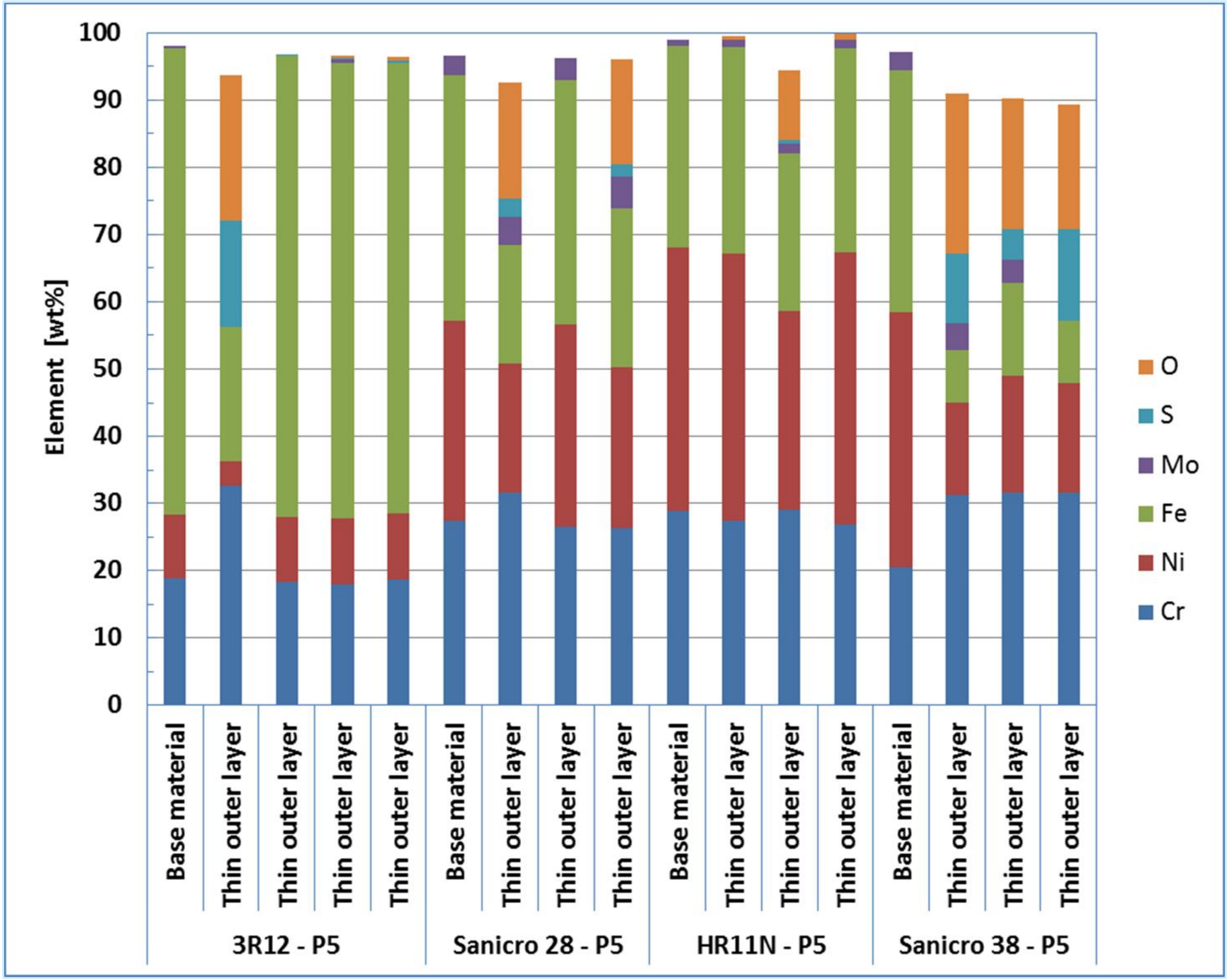


c) HR11N



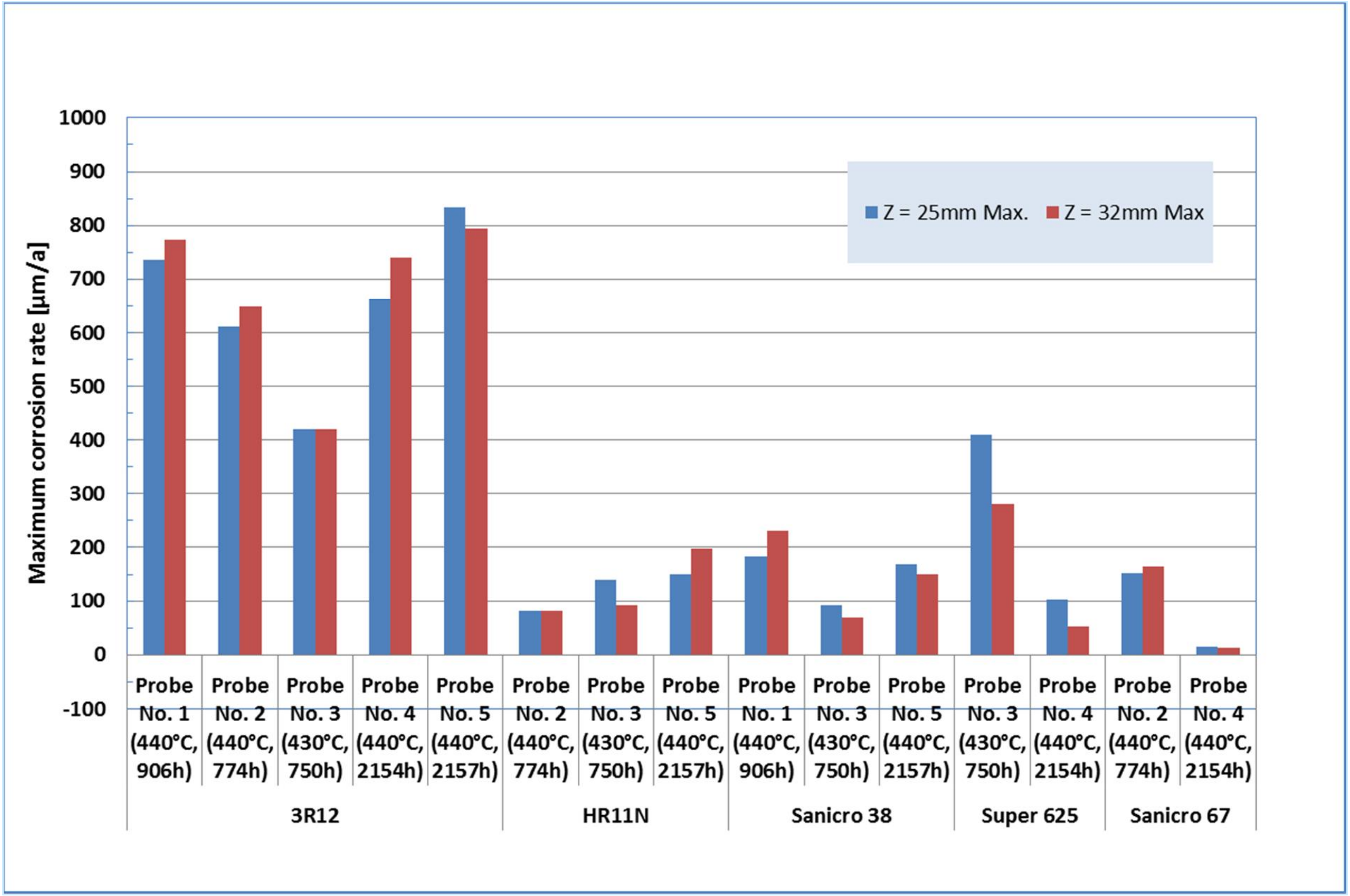
d) Sanicro 38

Probe test No. 5 – EDS analysis



Summary

Summary


Maximum corrosion rate [µm/a]
1000
900
800
700
600
500
400
300
200
100
0
-100
Z = 25mm Max.
Z = 32mm Max
Probe No. 1 (440°C, 906h)
Probe No. 2 (440°C, 774h)
Probe No. 3 (430°C, 750h)
Probe No. 4 (440°C, 2154h)
Probe No. 5 (440°C, 2157h)
3R12
Probe No. 2 (440°C, 774h)
Probe No. 3 (430°C, 750h)
Probe No. 5 (440°C, 2157h)
HR11N
Probe No. 1 (440°C, 906h)
Probe No. 3 (430°C, 750h)
Probe No. 5 (440°C, 2157h)
Sanicro 38
Probe No. 3 (430°C, 750h)
Probe No. 4 (440°C, 2154h)
Super 625
Probe No. 2 (440°C, 774h)
Probe No. 4 (440°C, 2154h)
Sanicro 67

Summary


Z = 25mm Max.
Z = 32mm Max
Maximum corrosion rate [µm/a]
500
400
300
200
100
0
-100
Probe No. 2 (440°C, 774h)
Probe No. 5 (440°C, 2157h)
Probe No. 1 (440°C, 906h)
Probe No. 5 (440°C, 2157h)
Probe No. 1 (440°C, 906h)
Probe No. 2 (440°C, 774h)
Probe No. 1 (440°C, 906h)
HR11N
Sanicro 38
3RE28
3XRE28
Sanicro 28

Summary

- Corrosion resistance in lower furnace conditions is improved by alloying, especially by chromium.
- According to the wall thickness measurements the test materials can be put in following order based on increased resistance:

  C-steel << 3R12 < HR11N ~ Sanicro 38 (~ Sanicro 28 ~ 3RE28/3XRE28) < Super 625 < Sanicro 67

- Carbon steel corroded at extremely high rate (>4 mm/a) at the temperature of 440 °C.
- 3R12 (AISI 304L) corrodes in such high rate (>0.6 mm/a) at 440 °C that it can't be safely used in the lower furnace in the future high pressure recovery boilers,

Summary

- Performance of the Sanicro 38 and HR11N was satisfactory in long term test at 440 °C (CR_{max} ~ 0.1...0.2 mm/a), but it is recommended to verify their performance also at lower temperature (400 °C).
- The new material group which looks promising is the high chromium alloys 3RE28/3XRE28 and Sanicro 28, but their long term performance should be verified in the future.
- If the corrosion resistance is the determining factor, the Sanicro 67 seems to be a good material for future boilers, since its corrosion rate was lowest from the studied alloys.
- Based on the long term test the Super 625 is the second best choice for the future high pressure boiler, but because of its relatively high corrosion rate in short term test more and longer tests are needed to verify its performance.

Summary

- In current samples the biggest problem was the specimen alignment i.e. it was impossible to measure the thickness profiles exactly from the same location before and after the test.
  - Some error to the measurement results; especially to the maximum corrosion rates
  - Most significant when samples had surface scratches and dents.
- Another factor that affected to the accuracy was the surface deposits that were not completely removed during washing.
- Tests showed that polishing together with longer exposure time improves the accuracy, both of which are recommended to be used in future tests and especially when evaluating highly alloyed materials.

VTT creates business from technology