

Comprehensive Laboratory Analysis of AC Coupon Test Stations

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ABSTRACT

In this paper, a test protocol for the laboratory analysis of the coupon test stations (CTSs) exposed to alternating current (AC) interference from the adjacent power lines was discussed in detail. Corrosion of coupons from the CTSs are mainly due to AC interference, corrosive soil, or microbiological induced corrosion (MIC). This paper provides an overview of corrosion issues commonly experienced by coupons and presents specific case histories involving AC interference, corrosive soil, and MIC. During the laboratory analysis, coupons were examined visually and photographed, studied under stereo microscope, and the coupons were also examined in detail using scanning electron microscope (SEM) and energy dispersive spectroscopy (EDS) in the as received condition and correspondingly after ultrasonic cleaning. The findings of the laboratory analysis are correlated with CTS historical data and relevant field inspection data to identify the actual cause of the corrosion of the CTSs.

In this paper, we will introduce our AC corrosion detector and a description of the concept in a simplified form. Our proprietary sensor can identify the extent of magnetite on the CTSs. The sensor correlates electric current measurement with the quantity of a predetermined iron oxide in the test coupon to determine a proxy for the degree of alternating current interference corrosion in the metallic structure.

Key words: AC current density, DC current density, AC interference, Magnetite, Soil corrosion, MIC, SEM, EDS.

INTRODUCTION

Several alternating current (AC) coupon test stations (CTS) located near AC power lines were investigated to assess the AC interference corrosion risk of the test coupons. As-received each AC test station consisted of two ½ inch (1.27 cm) diameter and 1-inch (2.54 cm) long carbon steel (CS) coupons. Coupons are much larger than 1 cm² and current density measurements are not 100% relatable to the SP21424 or ISO 18086 criteria, since these refer to measurements on (typically) 1 cm². The current densities measured on the coupons in this study will underestimate the AC corrosion threat.

One coupon was bonded to the pipeline – CP coupon and the other coupon is not connected to the pipeline – Native coupon. Figure 1 shows typical zinc ribbon connection to pipeline polarization cell replacement (PCR) with coupon test station. Figures 2 and 3 are photos of a new, pre-service CS3100 AC test station. Figure 2 shows that a typical AC test station consists of two test coupons (one native and one CP) enclosed in a reference tube. The geometry of the test coupons is described in Figure 3.

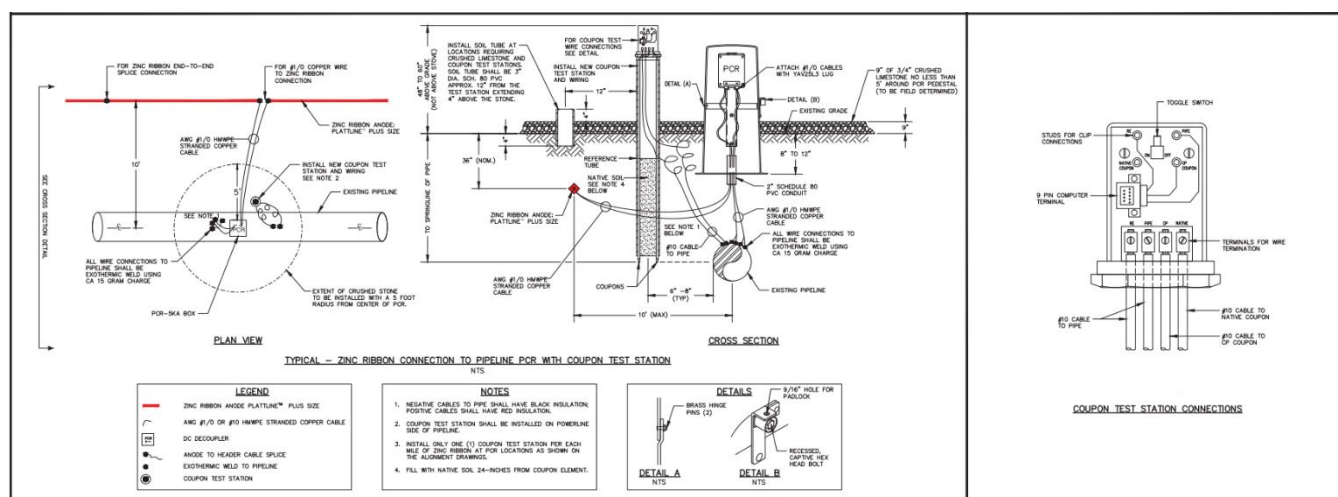


Figure 1: Typical zinc ribbon connection to pipeline PCR with coupon test station

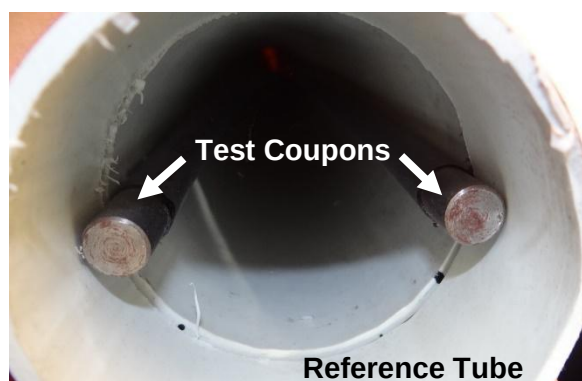


Figure 2: Photograph showing test coupons in a new AC Test Station that was not in service.

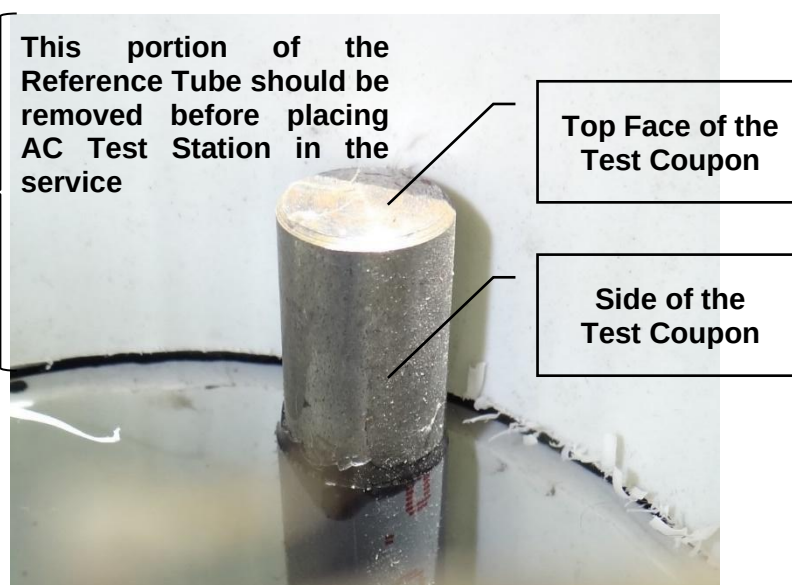


Figure 3: Closer view of one of the AC test station coupons showing the bare surface of the carbon steel to be exposed to soil.

SCOPE OF WORK

Comprehensive laboratory analysis was performed to determine if the coupons failed due to AC corrosion or other factors. The scope of work for comprehensive laboratory analysis was as follows:

1. Testing of AC coupons and corrosion deposits:
 - a) Visual examination of AC coupons in the as-received condition: This included detailed examination and observations related to deposits, scales, and other features; and supported with labeled photos.
 - b) Scanning electron microscopy [SEM] analysis of the AC coupons before and after cleaning.
 - c) Energy dispersive spectroscopy [EDS] elemental analysis of the AC coupons before and after cleaning.
2. Testing of soil samples:
 - a) Soil resistivity – both as-received and saturated.
 - b) pH, water-soluble chloride content, sulfide content, water-soluble sulfate content, % moisture, redox (oxidation-reduction) potential.
 - c) Corrosion rate – loss of thickness in mils per year [mpy] via linear polarization resistance (LPR).
 - d) Test for microbiologically-influenced corrosion. The testing c) & d) is relevant for soil corrosivity assessment.
3. Evaluation of the lab test results, assessment of background data (historical AC potential, DC potential, plus AC and DC current density reads), and overall metallurgical evaluation.

RESULTS

The results of the comprehensive laboratory analyses are presented below:

MP131.8335A

Background

Quarterly data from CTS location MP131.8335A collected over its lifetime, including historical AC potential, DC potential, plus AC and DC current density reads were analyzed. Historical AC potential was in the range 0.023 – 1.365 V. Historical DC potential (ON) reads were plotted with respect to date and time of data collection (Figure 4). The main observation from the plot was that the DC potential reads of CTS location MP 131.8335A met the -850 mV minimum NACE CP criterion. Review of inline inspection (ILI) report revealed that the observed external corrosion features were below the threshold for repair.

Calculated Current Density Based on Coupon Surface Area

AC and DC current densities are plotted in Figure 5. Table 1 shows DC current density data and Table 2 shows AC current density data.

According to “NACE ⁽¹⁾ SP21424-2018: Alternating Current Corrosion on Cathodically Protected Pipelines: Risk Assessment, Mitigation and Monitoring”, the AC current density should not exceed a time-weighted average of either: ¹

- 30 A/m² if DC current density exceeds 1 A/m²; or
- 100 A/m² if DC current density is less than 1 A/m²

¹⁰ NACE International, 15835 Park Ten Place, Houston, Texas 77084.

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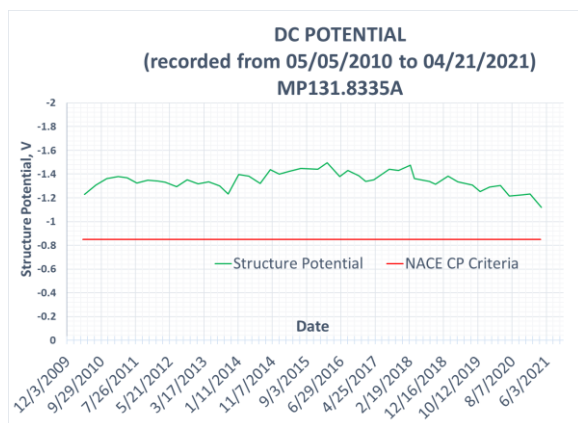


Figure 4: Plot showing structure ON-potential data of the CTS at location MP131.8335A recorded from 05/05/2010 12:00 to 04/21/2021 12:35. From the plot, it is evident that potential reads meet the -850mV minimum NACE CP criterion for the entire part in service.

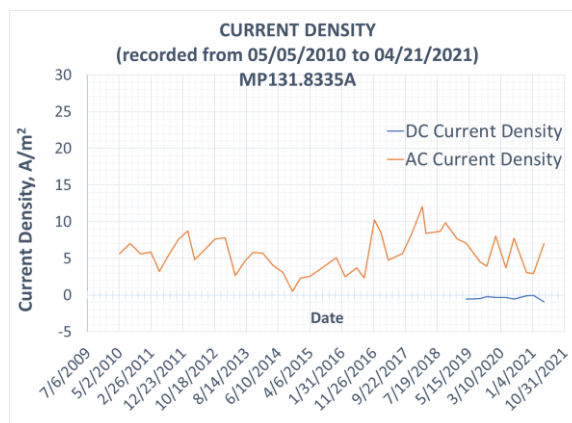


Figure 5: Plot showing measured AC and DC current densities of the CTS at location MP131.8335A recorded from 05/05/2010 12:00 to 04/21/2021 12:35. From the plot, it is evident that DC current density is below 1 A/m² and AC current density has not exceeded 30 A/m².

From Table 1:

- The average DC current density of CTS location MP131.8335A did not exceed 1 A/m²; therefore, the AC current density can be controlled to less than 100 A/m².

Table 1. DC Current Density Data in A/m²

Serial No.	Description	Value
1	Minimum coupon DC current density of the CTS at location MP131.8335A recorded from 04/18/2019 09:28 to 04/21/2021 12:35.	-0.94
	Average coupon DC current density of the CTS at location MP131.8335A recorded from 04/18/2019 09:28 to 04/21/2021 12:35.	-0.38
	Maximum coupon DC current density of the CTS at location MP131.8335A recorded from 04/18/2019 09:28 to 04/21/2021 12:35.	-0.02

From Table 2:

- DC current density was measured beginning in 2019. Both average and maximum AC current density values from 2019 were under 30 A/m², indicating a low risk of AC corrosion given existing AC mitigation.

Table 2. AC Current Density Data in A/m²

Serial No.	Description	Value
1	Minimum coupon AC current density of the CTS at location MP131.8335A recorded from 05/05/2010 12:00 to 04/21/2021 12:35.	0.52
	Average coupon AC current density of the CTS at location MP131.8335A recorded from 05/05/2010 12:00 to 04/21/2021 12:35.	5.77
	Maximum coupon AC current density of the CTS at location MP131.8335A recorded from 05/05/2010 12:00 to 04/21/2021 12:35.	12.09

Laboratory Testing of Coupons

The test coupons were sectioned from the AC test station for visual examination. Figure 6 shows that the top face of the native coupon was covered with firmly adhered soil, and the top face of the CP coupon exhibited reddish-brown deposits. Figure 7 shows the side faces of the native and CP test coupons. The features on the top face and the sides of the test coupons are similar, i.e., the side of the native coupon was covered with firmly adhered soil, and the top face of the CP coupon exhibited reddish-brown deposits.

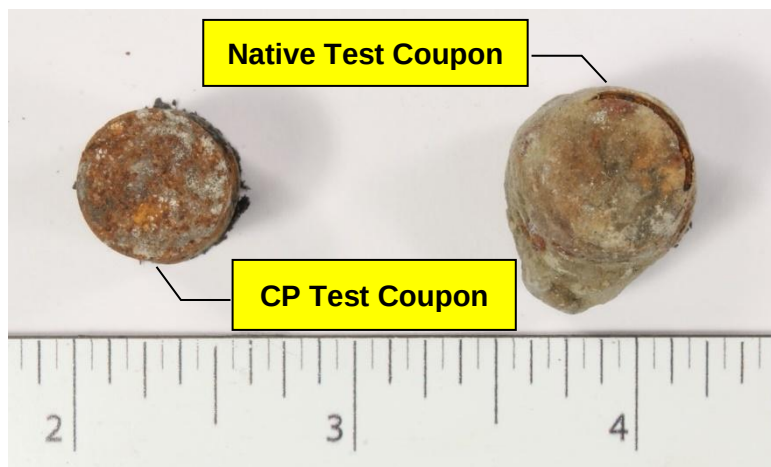


Figure 6: Photograph showing cut sections of the CP & native test coupons from the test station.

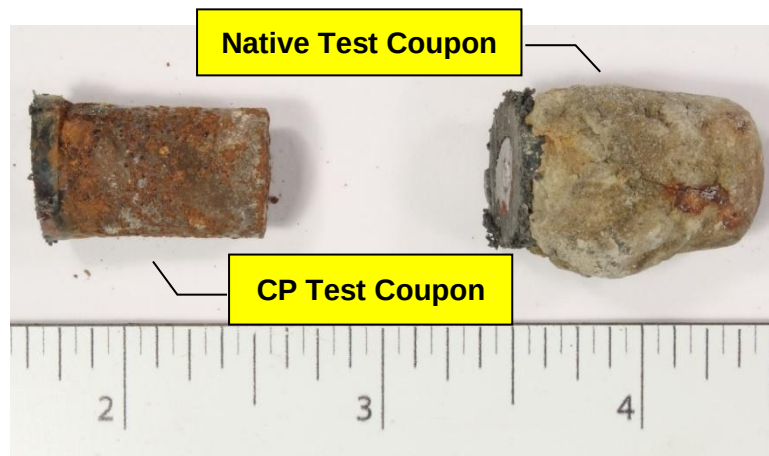


Figure 7: Photograph showing cut sections of the CP & native test coupons from the test station.

Table 3. Summary of EDS Data – CTS Location MP131.8335A

Coupon Type	Location Analyzed on Coupon	Spot	Reference to Figure ...	Elements Detected		
				Major (>5 wt. %)	Minor (≤5 wt. %, >0.5 wt. %)	Trace (≤0.5 wt. %)
Native	Top face	Selected Area 1	8	O, Na, Si, Fe, Cl	Al, S, Ca	--
CP	Top face (a)	Selected Area 1	9	O, Na, Si, Fe	Mg, Al, Cl, K, Ca	--
Native	Side	Selected Area 1	10	O, Na, Si, Fe, Ca, Cl	Mg, Al, S, K	--
CP	Side (b)	Selected Area 1	11	O, Na, Fe	Mg, Al, Si, Ca, Cl	K, S
CP	Top face within corrosion pit (c)	8	22	C, O, Fe	Al, S	Si, P, Mn
CP	Top face away from corrosion pit (d)	3	23	Fe	O, Mn	--
CP	Side	Full Area 1	24	Fe	Mn	Si

(a) The presence of chlorine (chloride ions) on the top face of the CP coupon suggests that it may not have received CP at some point in service. However, absence of significant metal loss and no readily apparent pitting indicates that CP in place was effective for much of the time. Also, it is possible that the CP coupon became soaked and contaminated with adjacent chloride-rich soil as it rained during the excavation. The other reasonable possibility was that the soil surrounding the coupons was wet much of the time due to a high groundwater table.

(b) See Note (a) above.

(c) Sulfur was detected in the pits.

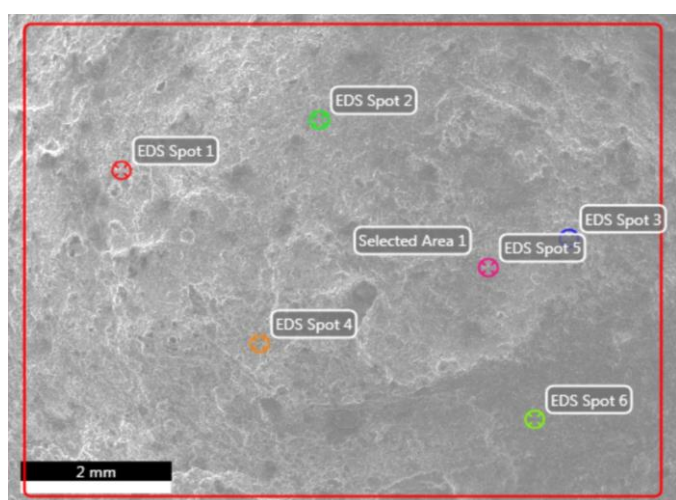
(d) Sulfur was not detected in unaffected areas, suggesting that the observed pitting was due to microbial activity.

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Elemental (EDS) elemental analysis as summarized in Table 3 showed the following:

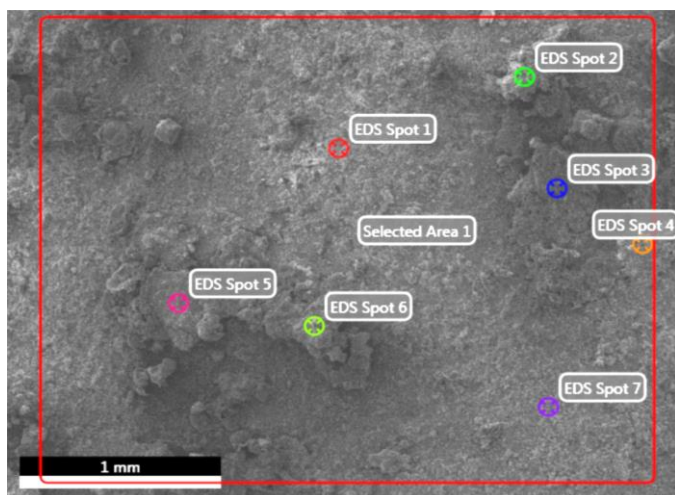
- Selected Area 1 on the deposits at the *top face of the native test coupon* showed calcium (earth alkaline cations); sodium and aluminum (both soil alkaline cations); along with iron. Silicon and oxygen (representing earth's crust) were also detected, plus sulfur and significant amounts of chlorine (Figure 8).
- Selected Area 1 located on the deposits at the *top face of the CP test coupon* contained calcium, magnesium, sodium, aluminum, potassium, iron, silicon, and oxygen. Chlorine was also detected (Figure 9).
- Selected Area 1 on the deposits at the *side of the native test coupon* contained calcium, magnesium, sodium, aluminum, potassium, iron, silicon, and oxygen, plus sulfur and significant amounts of chlorine (Figure 10).
- Selected Area 1 located on the deposits at the *side of the CP test coupon* contained calcium, magnesium, sodium, aluminum, potassium, iron, silicon, and oxygen. Sulfur and chlorine were also detected (Figure 11).



Element	Weight %	Atomic %
O	13.67	22.88
Na	29.73	34.62
Al	1.21	1.20
Si	7.25	6.91
S	1.38	1.15
Cl	36.83	27.80
Ca	3.67	2.45
Fe	6.27	3.01

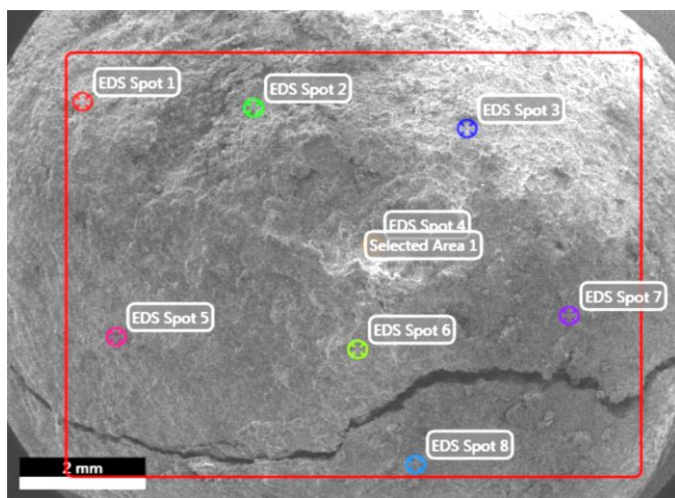
Element	Weight %	Atomic %
O	13.67	22.88
Na	29.73	34.62
Al	1.21	1.20
Si	7.25	6.91
S	1.38	1.15
Cl	36.83	27.80
Ca	3.67	2.45
Fe	6.27	3.01

Figure 8: EDS data (selected area 1 – red box) taken on the soil deposit present at the top face of the native test coupon showing calcium (earth alkaline cations), sodium, and aluminum (soil alkaline cations) along with iron. Silicon and oxygen (Earth's crust) were also detected. Sulfur and significant amounts of chlorine were also detected.



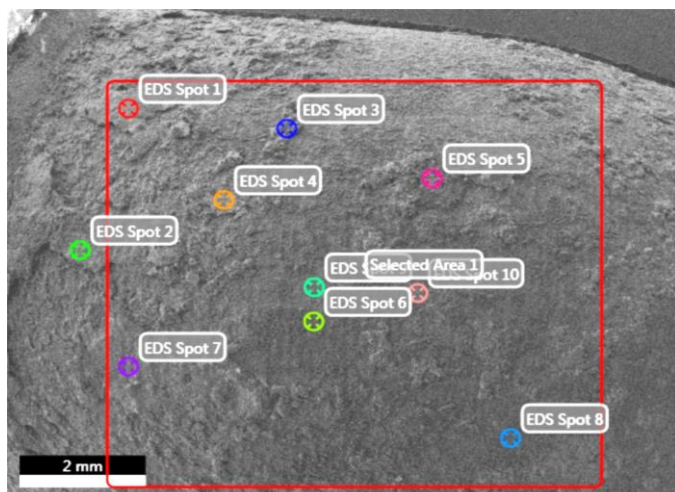
Element	Weight %	Atomic %
O	28.25	47.54
Na	17.45	20.44
Mg	1.01	1.12
Al	1.93	1.92
Si	5.70	5.47
Cl	2.41	1.83
K	0.87	0.60
Ca	3.47	2.33
Fe	38.90	18.75

Figure 9: EDS data (selected area 1 – red box) taken on the deposits at the top face of the CP test coupon showing calcium and magnesium (earth alkaline cations), sodium, aluminum, and potassium (soil alkaline cations) along with iron. Silicon and oxygen (Earth’s crust) were also detected. Noticeable presence of chlorine was also detected.



Element	Weight %	Atomic %
O	25.45	39.57
Na	20.49	22.17
Mg	1.10	1.13
Al	3.03	2.79
Si	11.20	9.92
S	1.14	0.89
Cl	21.76	15.26
K	1.07	0.68
Ca	5.78	3.59
Fe	8.97	3.99

Figure 10: EDS data (selected area 1 – red box) taken on the deposit from the side of the native test coupon showing calcium and magnesium (earth alkaline cations), sodium, aluminum, and potassium (soil alkaline cations) along with iron. Silicon and oxygen (Earth’s crust) were also detected. Sulfur and significant amounts of chlorine were also detected.



Element Weight % Atomic %

O	25.59	44.19
Na	21.66	26.03
Mg	0.99	1.12
Al	1.01	1.03
Si	2.91	2.86
S	0.19	0.17
Cl	2.76	2.15
K	0.30	0.21
Ca	0.96	0.66
Fe	43.63	21.58

Figure 11: EDS data (selected area 1 – red box) taken on the deposits from the side of the CP test coupon showing calcium and magnesium (earth alkaline cations), sodium, aluminum, and potassium (soil alkaline cations) along with iron. Silicon and oxygen (Earth's crust) were also detected. Traces of sulfur and noticeable presence of chlorine were also detected.

Figures 12 through 13 show the condition of the test coupons after ultrasonic cleaning. The coupons were cleaned to remove firmly adhered corrosion deposits and perform EDS on the cleaned coupons. Figure 12 shows corrosion attack on the top face of the native test coupon, whereas the CP test coupon was relatively unaffected because CP was protecting it. However, staining due to corrosion attack was noted on the top face of the CP test coupon. Figure 13 shows the condition of the test coupon sides after cleaning. The native coupon was significantly corroded, while only superficial corrosion attack was observed on the side of the CP coupon.



Figure 12: Photograph showing cut sections of the CP & native test coupons from the test station after ultrasonic cleaning.

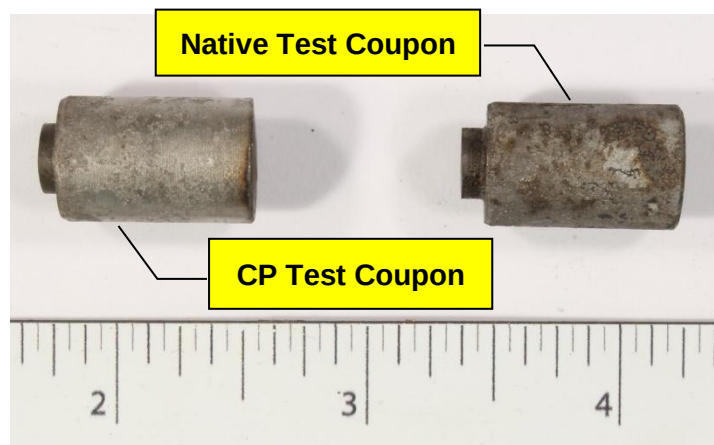


Figure 13: Photograph showing cut sections of the CP & native test coupons from the test station after ultrasonic cleaning.

Figures 14 and 15 show metal loss on the side of the cleaned, native test coupon at higher magnifications. Figures 16 and 17 show the condition of the side of the CP test coupon. Shallow corrosion attack was observed on the side of the CP coupon. Figures 18 and 19 show significant metal loss on the top face of