Comparison of the Corrosion Protection Effectiveness of Vapor Corrosion Inhibitors and Dry Air System

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Concern issues

- In atmospheric corrosion, a material is continuously subjected to air moisture and corrosive species (pollutants).
- The vast majority of natural degradation is uniform, and atmospheric corrosion is probably the most prevalent type.
- Preservation and mothballing equipment during short term or long term storage is extremely important to maintain access and military preparedness.

- Common techniques used to reduce humidity or isolate the metal from moisture including physical barriers, such as paints and lubricants will lessen the corrosion rate significantly. Concern for the environment and desire to minimize use of hazardous chemicals has led to system modernization and the development of new technologies for barrier coatings.
- An alternative approach, controlled humidity protection, focuses on the air moisture, specifically relative humidity (RH). Elimination of moisture is critical for suppressing the corrosion rate in atmospheric corrosion. By extracting moisture from the air, RH can be reduced to a level where surface wetness cannot form. The processed dry air is then recirculated around the equipment.
- Dehumidification is effective, it has been determined that steel is much less likely to corrode in environments with less than 40% humidity. However, reducing the temperature does not always help and reducing the pollutant concentration is not always achievable.

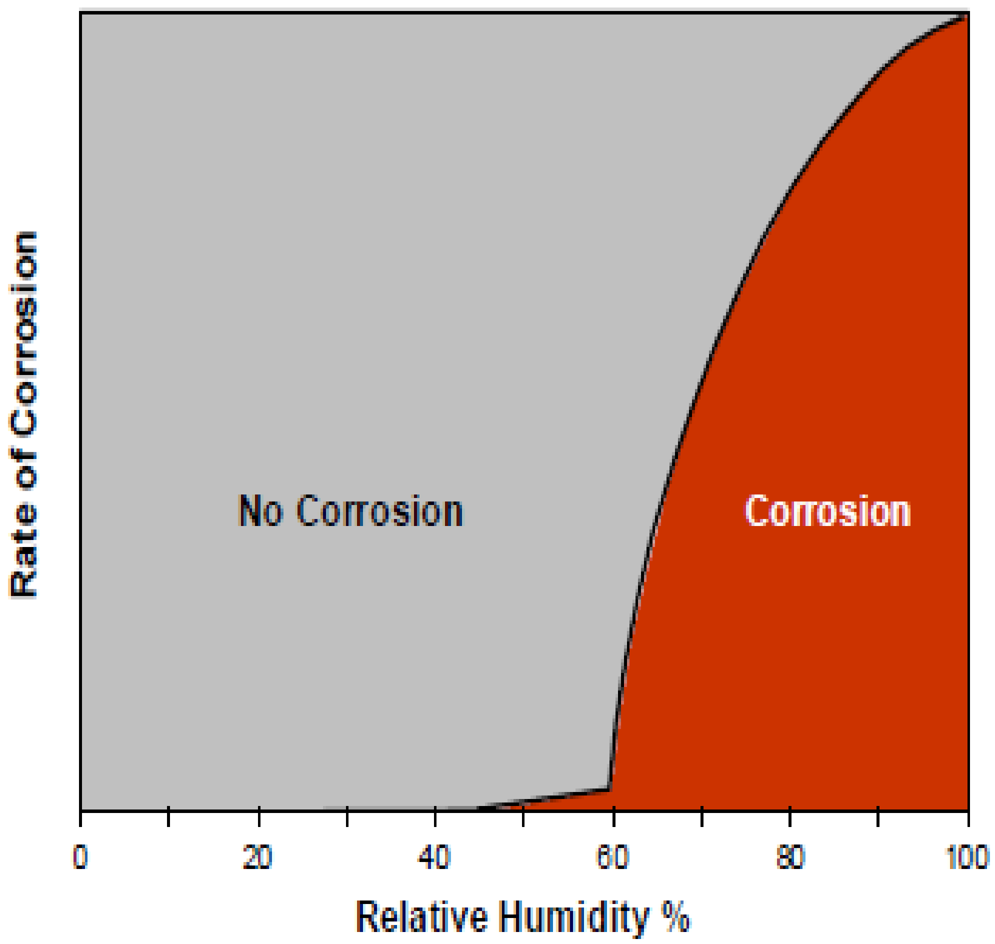
- Controlled Humidity Protection (CHP) has been extensively evaluated and is applied by many nations as a maintenance technology for operational weapon systems.
- Within department of Defense (DoD), the Army National Guard is a proponent for applying CHP to its weapon systems.
- Many foreign defense forces currently use CHP as a maintenance technology for their operational weapon systems. An industry analysis of eleven European defense forces revealed that the majority have instituted CHP technology in both operational and longer-term applications.

- The tangible benefits of CHP as a maintenance technology can include reduced ownership costs for weapon systems and equipment, and increased readiness and sustainability.

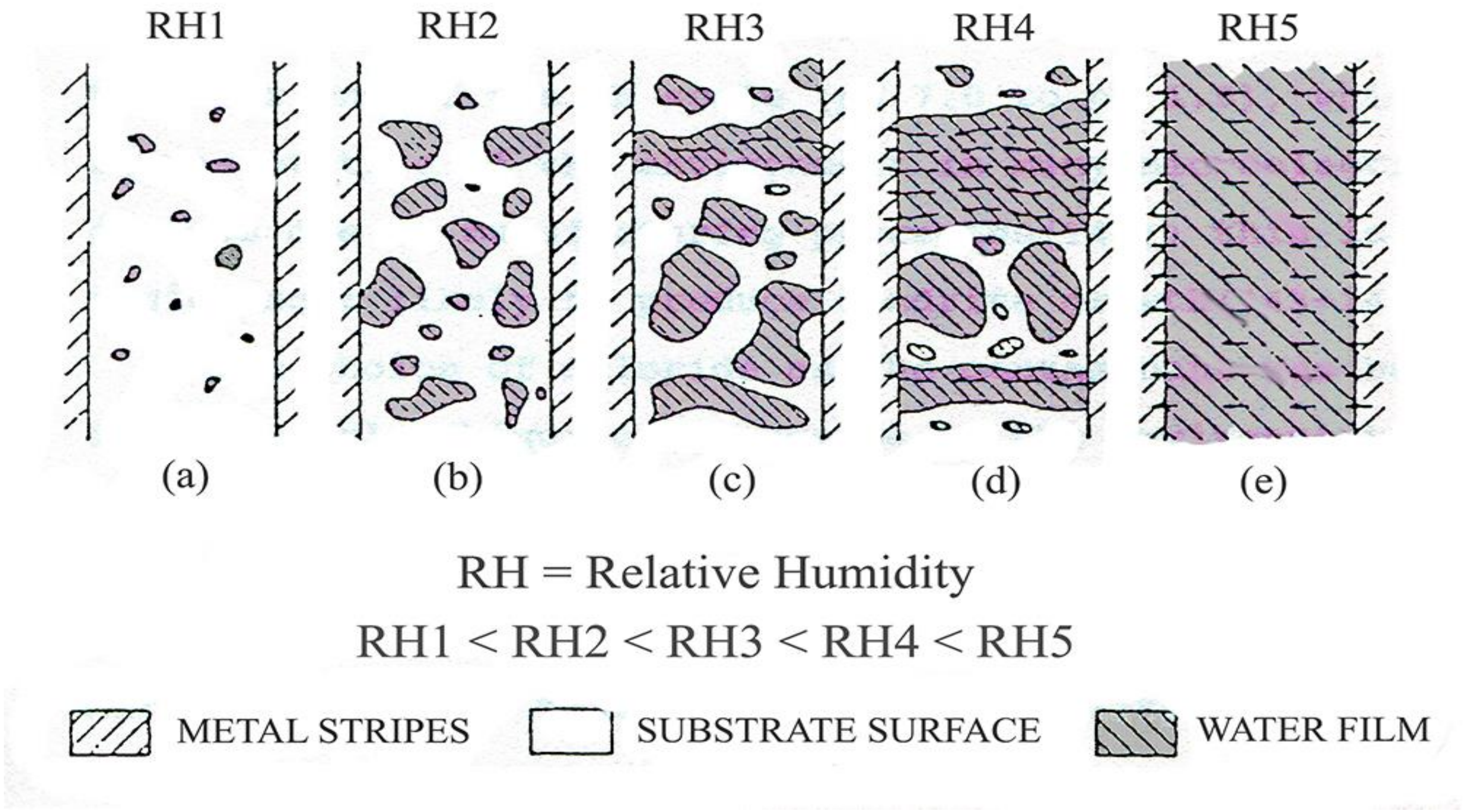
- Despite positive data, localized corrosion attacks have been reported for this method of corrosion protection. When a system is breached and pollutants or contamination enter the dry air system, localized corrosion can occur.

Between 40% and 60% RH corrosion can occur, but at a very low rate.
When the relative humidity exceeds 60% the rate of corrosion increases dramatically.

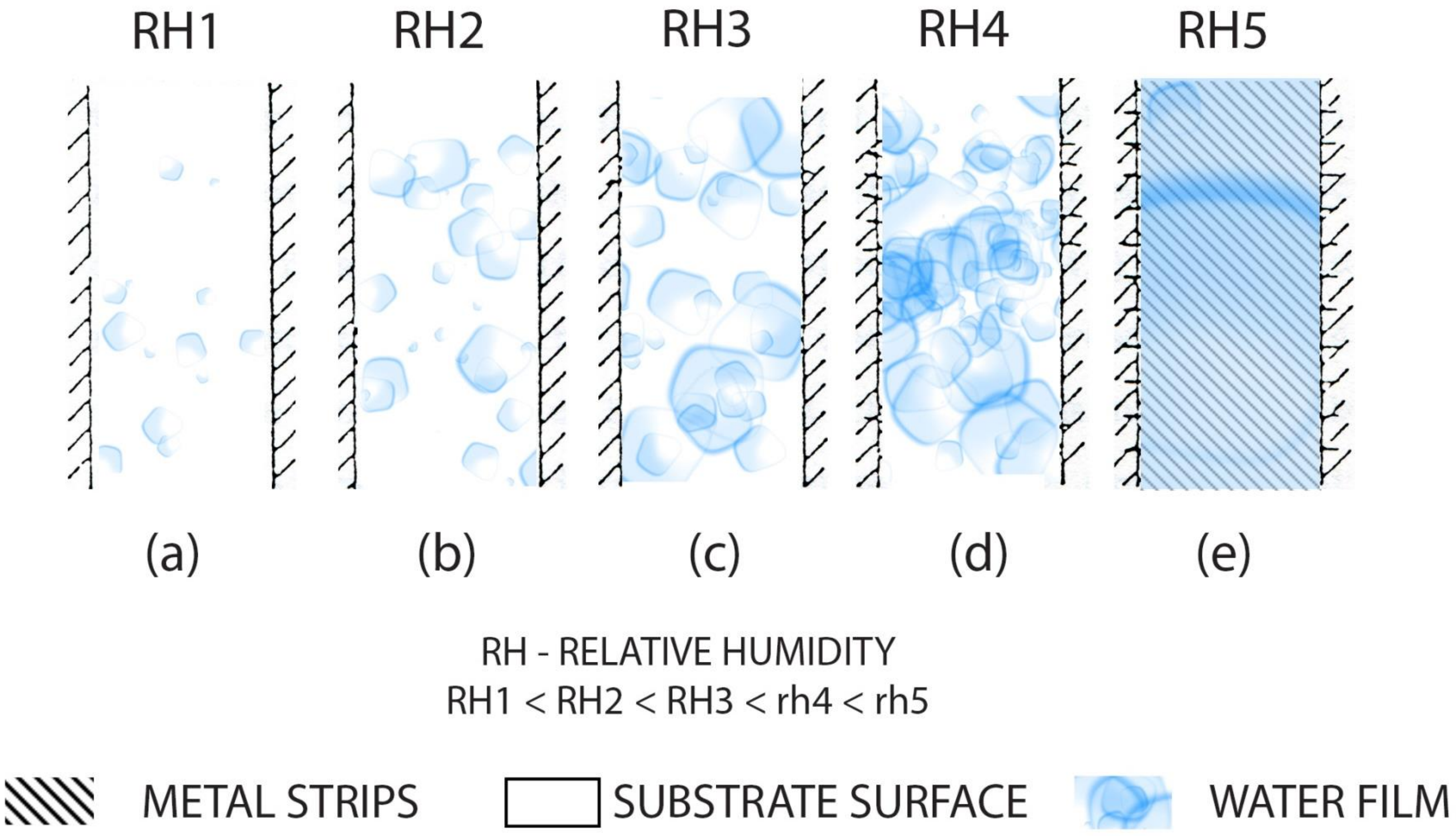
Prof. H. H. Uhlig (MIT Corrosion Laboratory)



Effects of RH% on Water Condensation on a substrate surface



Effects of RH% on Water Droplet formation on surface



Concern for infrastructures & suspension Bridges

- Corrosion of main cables on suspension bridges is a major problem on a world-wide basis. The load-carrying wires are covered by wrapping wire and corrosion is therefore hidden and often progresses to a very serious level before it is detected.

- Many examples have illustrated that traditional corrosion protection systems for main cables do not prevent corrosion, but generally slows it down.

- This has led to the development and application of VCI system in addition to dehumidification system of main cables, which truly prevents corrosion.

- A dehumidification system blows dry air through the main cables and keeps the atmosphere in the cables so dry that corrosion cannot occur (RH% <40). However, in most cases dehumidification system alone can not stop corrosion.

Project Objective

- Corrosion behavior of carbon steel and galvanized steel samples were investigated using the Controlled Humidity Protection (CHP) with two different protection mechanisms:

  - **Dry Air system RH% <40%**
  - **Vapor corrosion inhibitor* + Dry Air (<40% RH)**

*Using commercially available VCI product.

- To demonstrate which technique provides more protection in corrosive environments, especially where there are localized corrosion dominant such as restricted geometries: crevices, threads, notches and under-deposits.

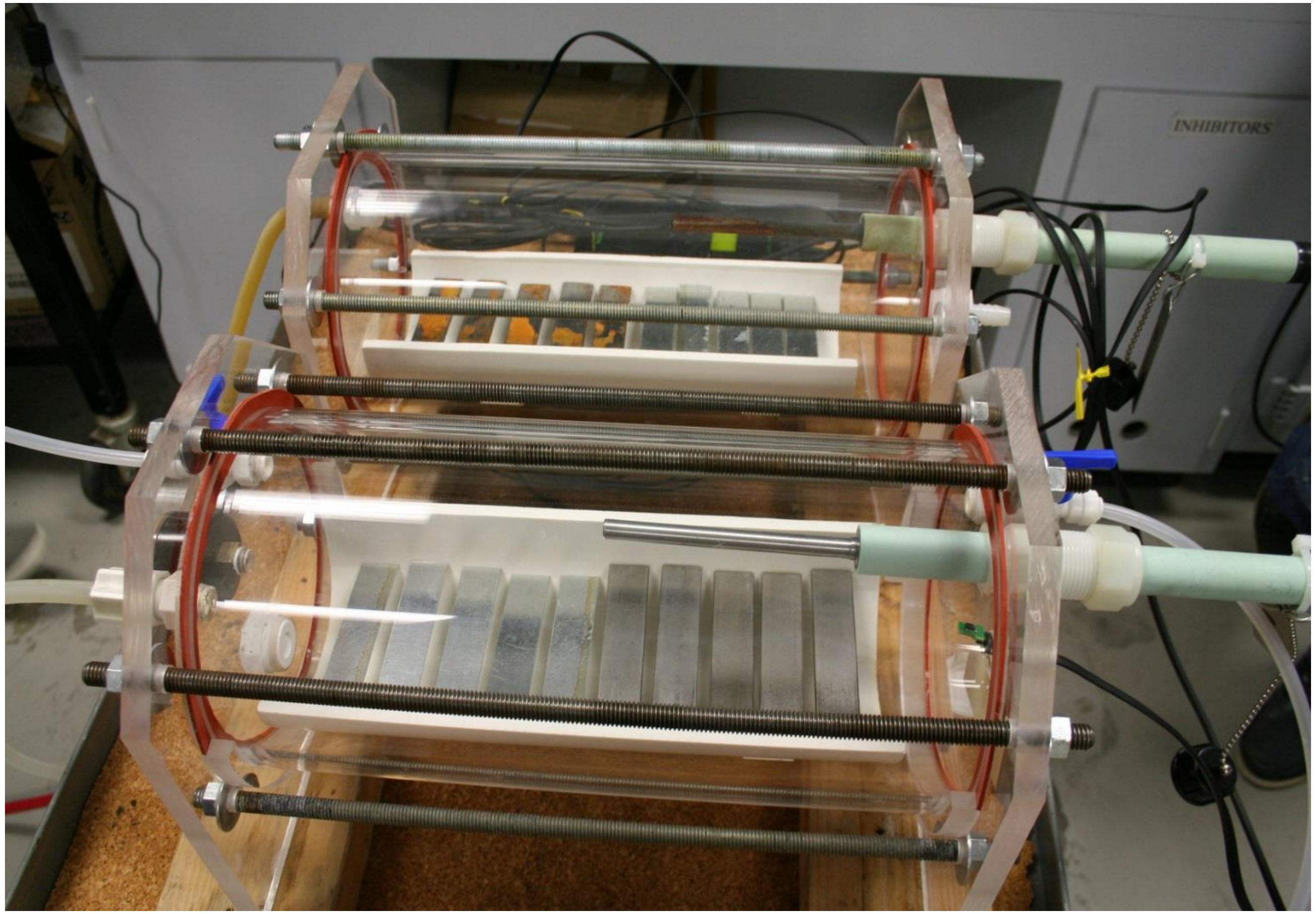
Experimental Procedures

- Corrosion behavior of carbon steel and galvanized steel samples were studied in two different controlled humidity protection conditions;
- 200 ppm chloride solution + 10% inhibitor (VCI),
- 200 ppm chloride solution

Solutions were injected into the environment every 48 hours with a constant flow of dry air at less than 40% RH and 20 psi.

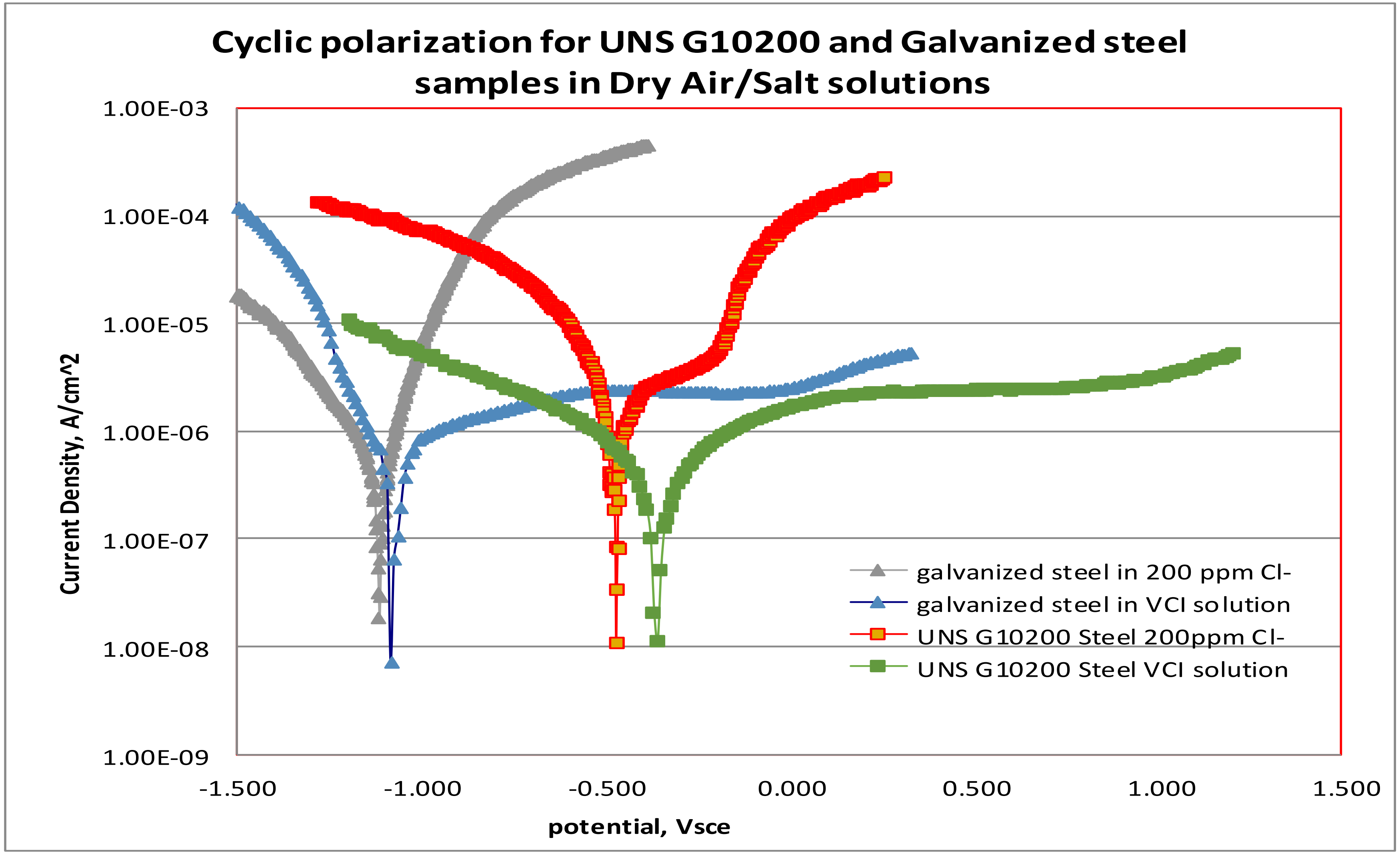
The corrosion rate of the exposed samples were monitored for more than six months (roughly 4,500 hours) using electrical resistance (ER) probe techniques.

Test Setup for Corrosion Performance of using the Controlled Humidity Protection (CHP)

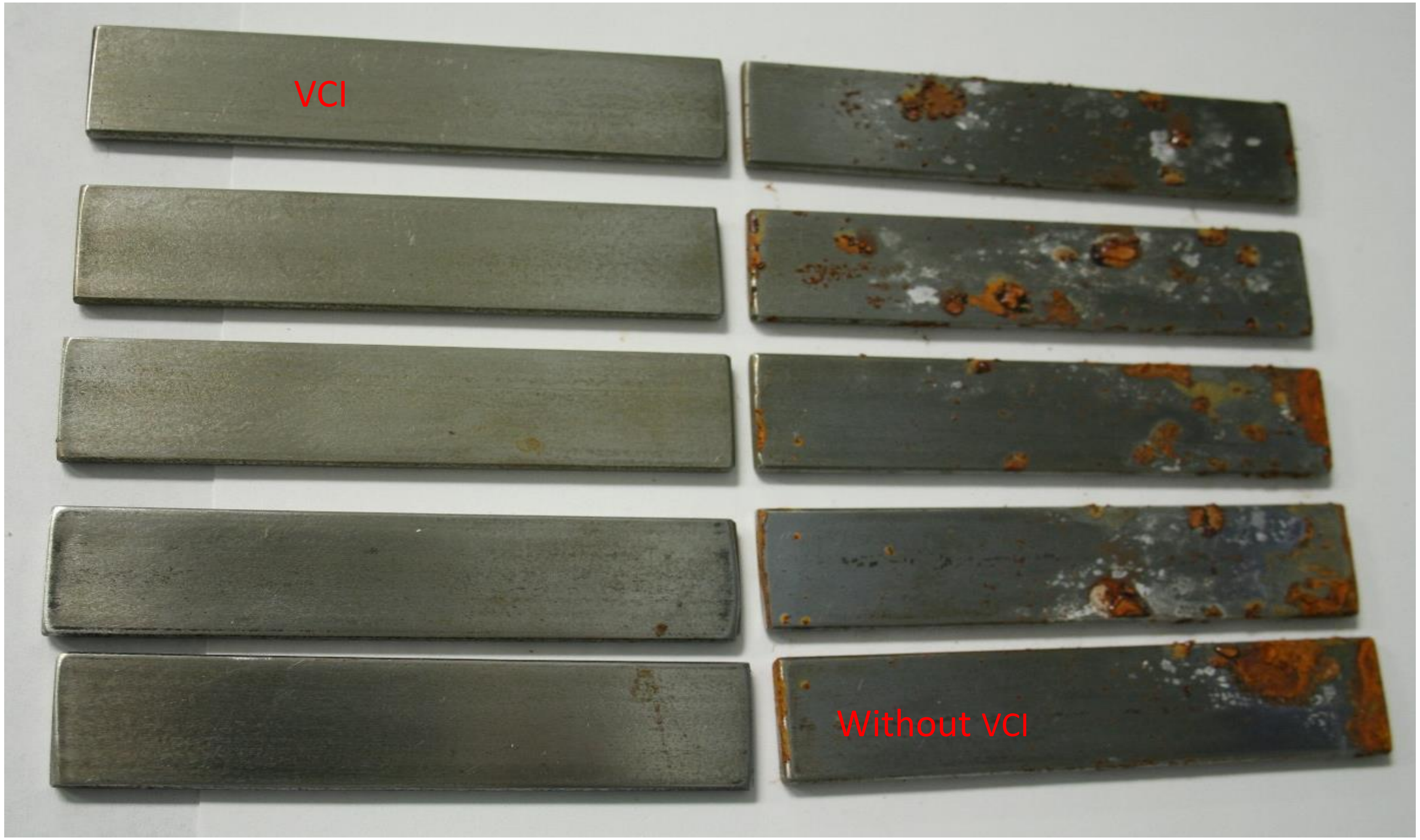


Test Setup for Corrosion Performance of using the Controlled Humidity Protection (CHP)

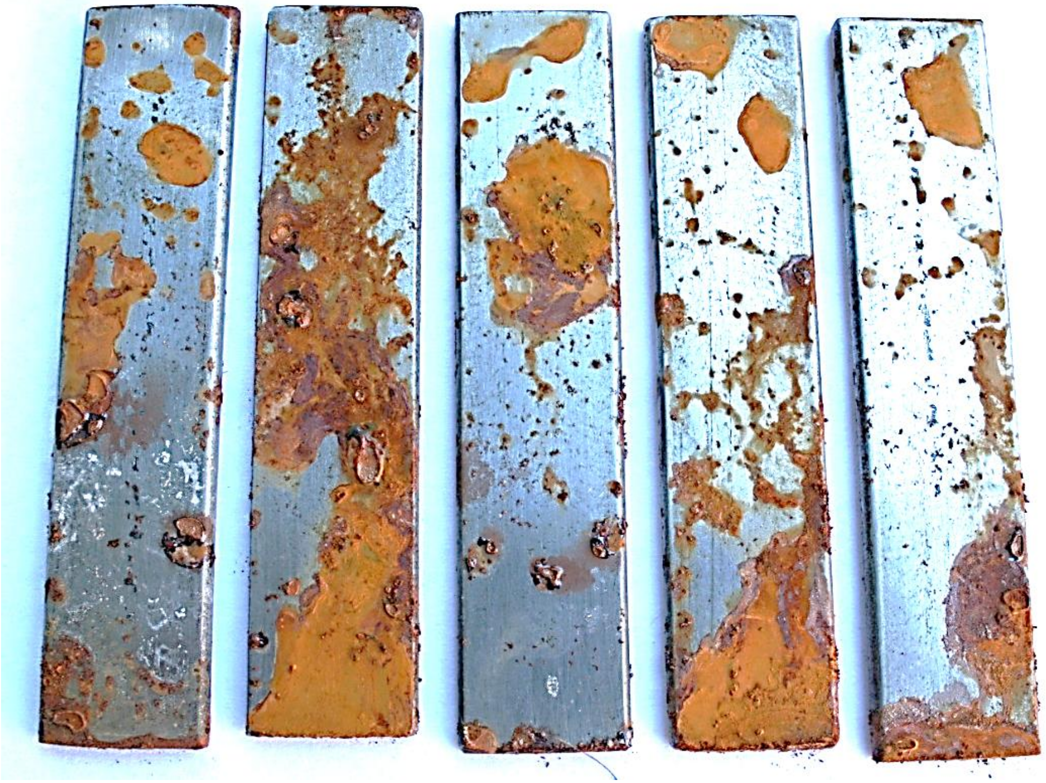
Electrochemical polarization behavior of the UNS G10200 steel samples in 10% VCI and dry air in 200 ppm chloride ion solution

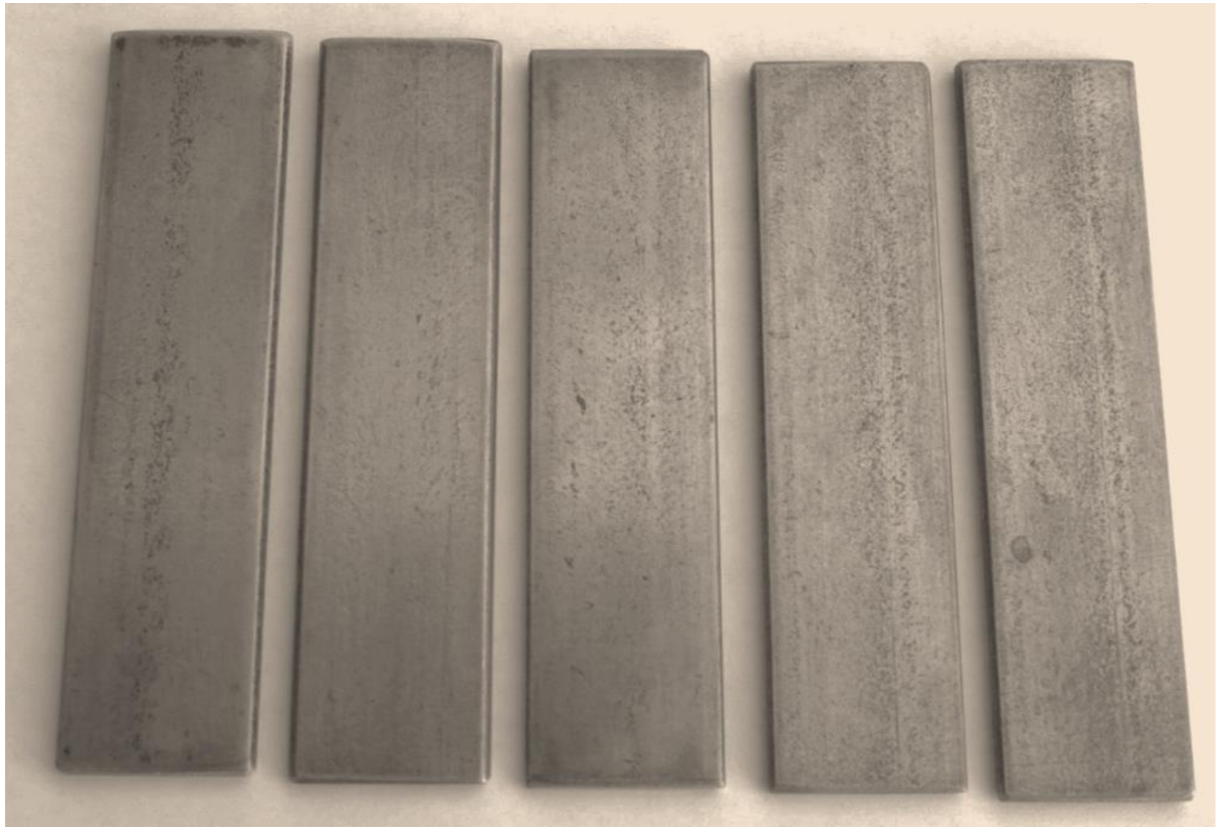


Comparison of Dry Air and VCI+ Dry Air Dry, Day 32



Comparison of Dry Air and VCI+ Dry Air Dry, Day 64



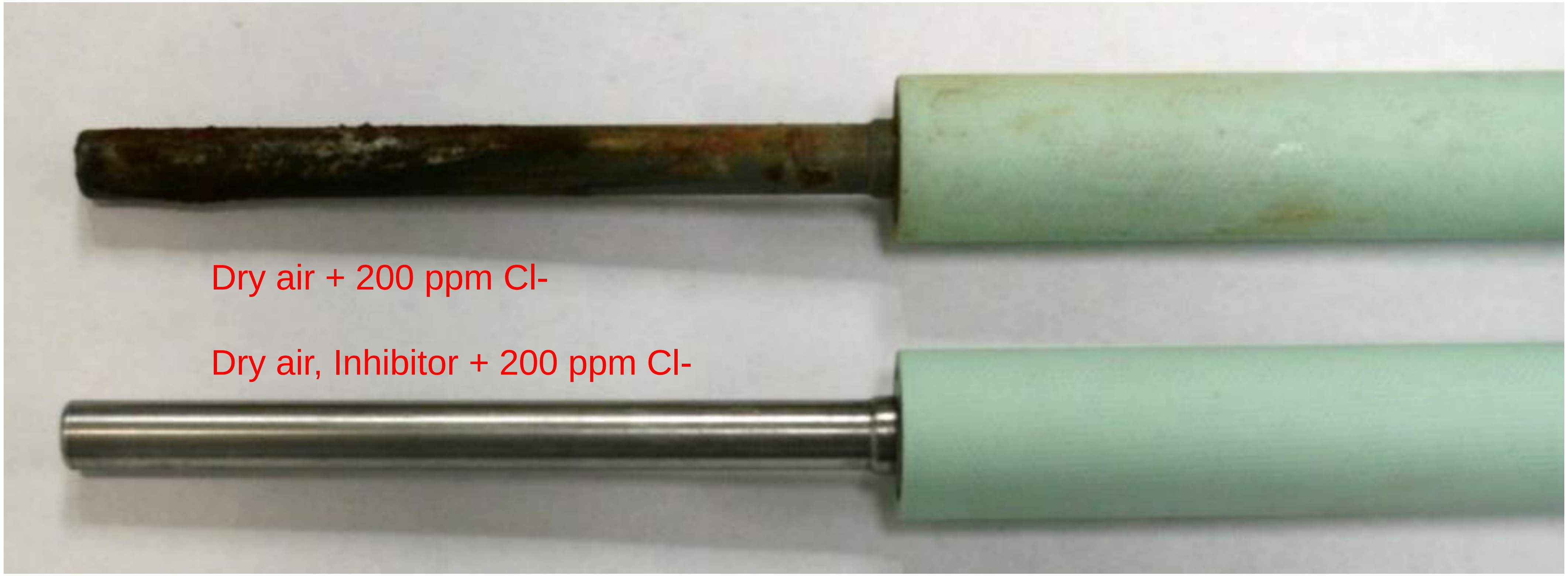


ER probes after 1,536 hours (64 days) exposure, top probe exposed to dry air, lower probe protected with inhibitor.

Carbon steel and galvanized steel samples exposed to VCI+ Dry Air Dry, Day 64

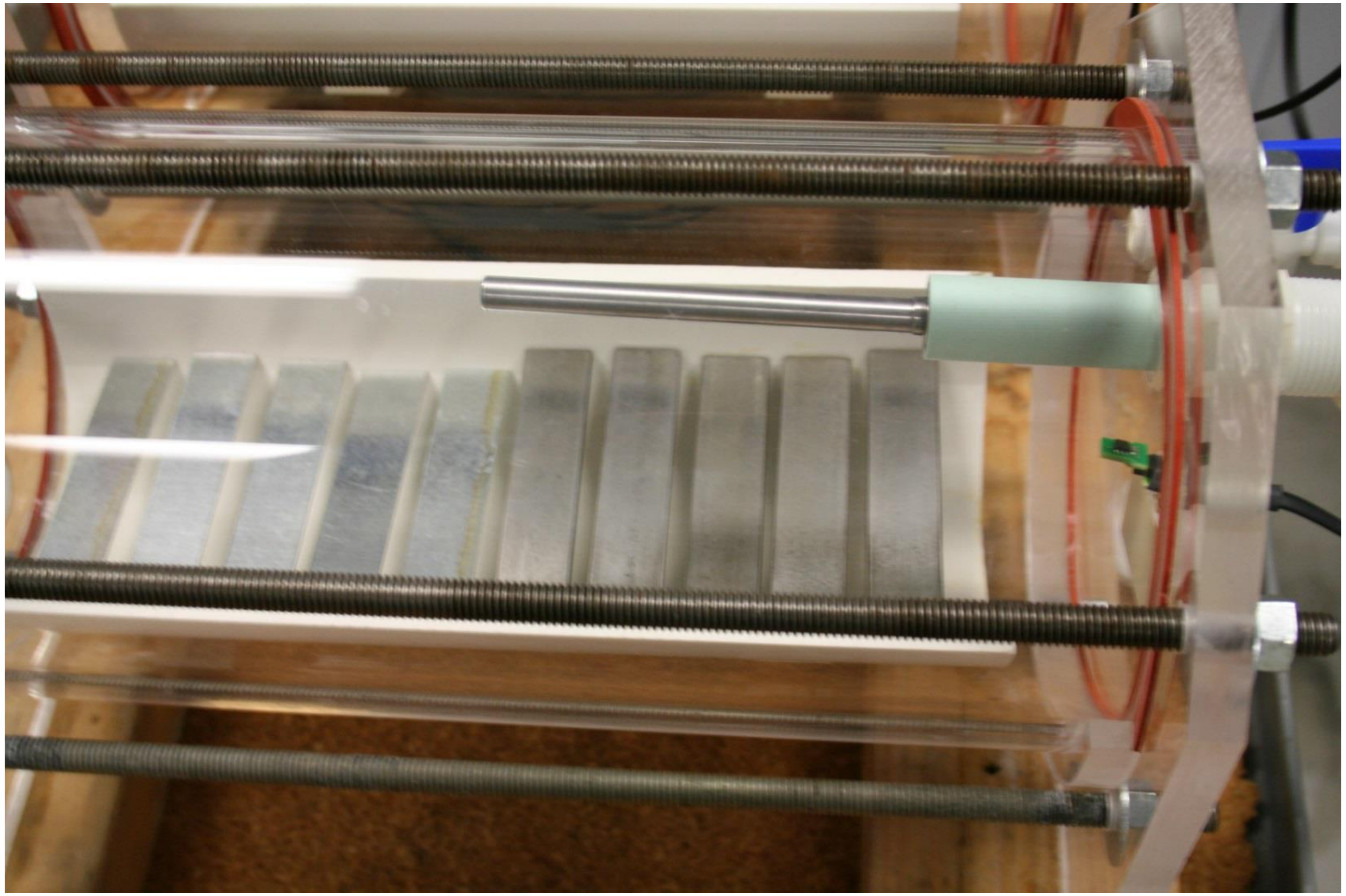
VCI exposed samples were corrosion free.

ER probes after 2884 hours (120 days) exposure, top probe exposed to dry air, lower probe protected with inhibitor.



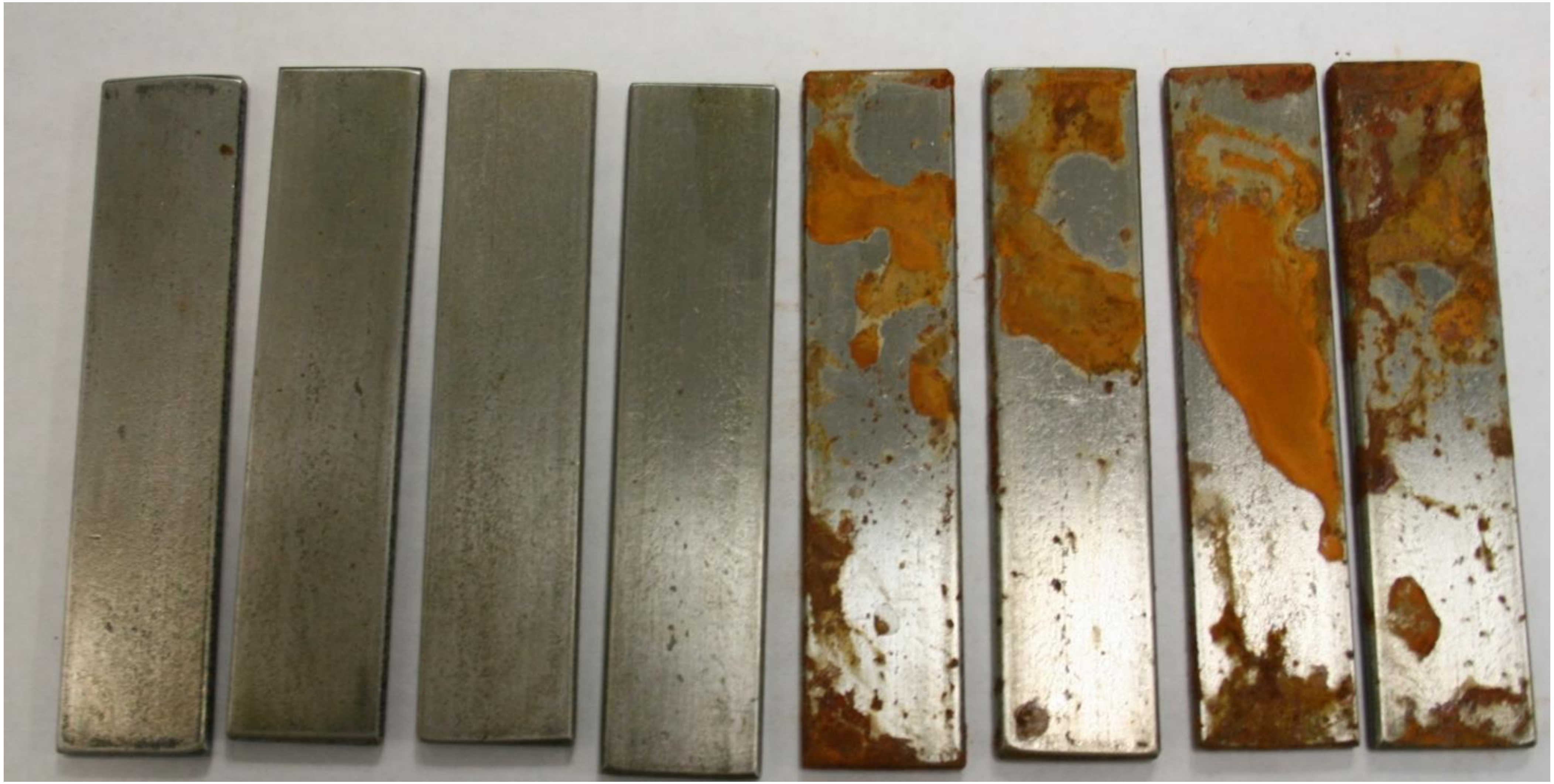
Dry Air+ 200 ppm Cl-, Day 120

VCI protected samples, Day 120
VCI +200 ppm Cl-

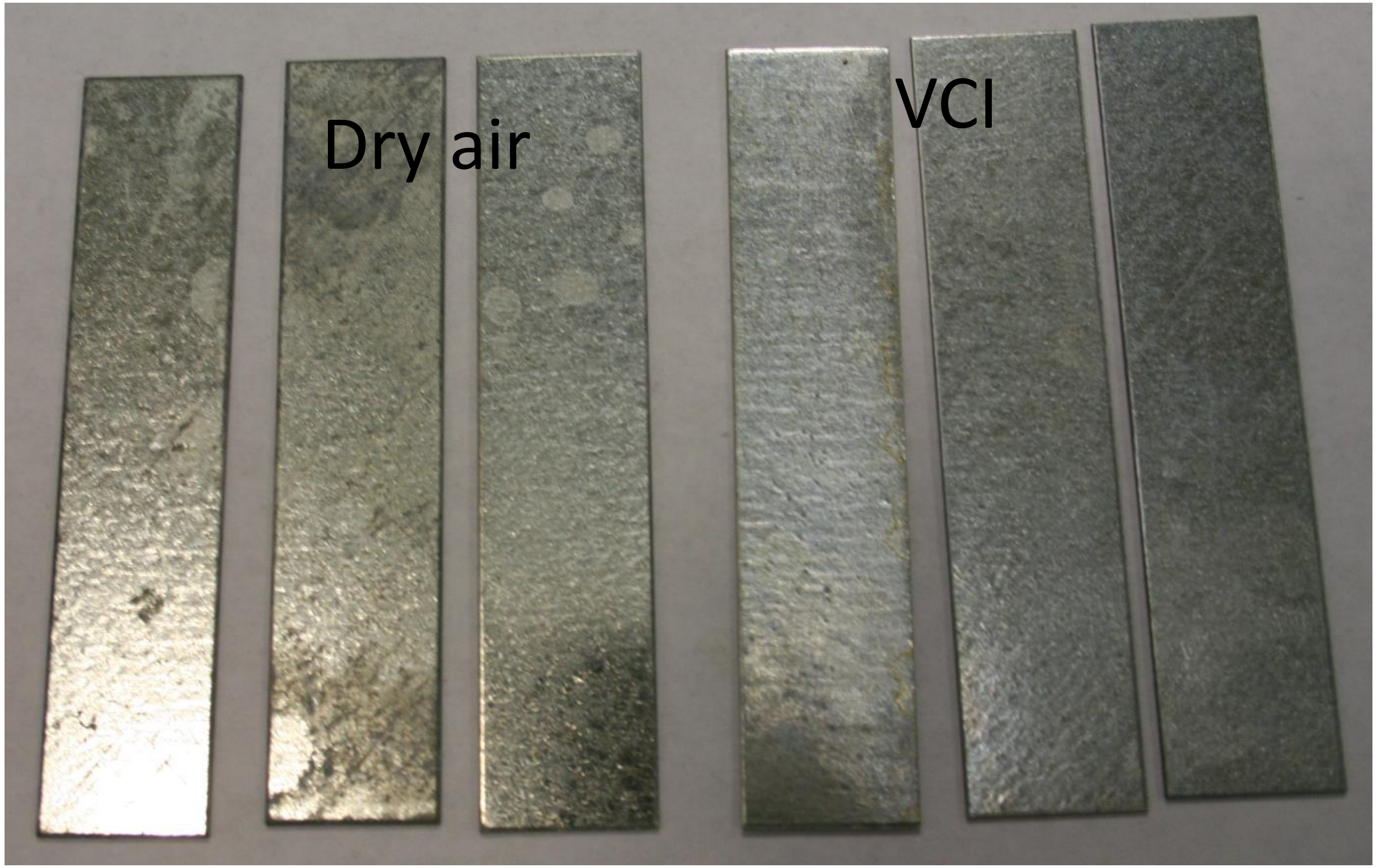


Surface conditions of exposed samples to Dry Air, Day 120

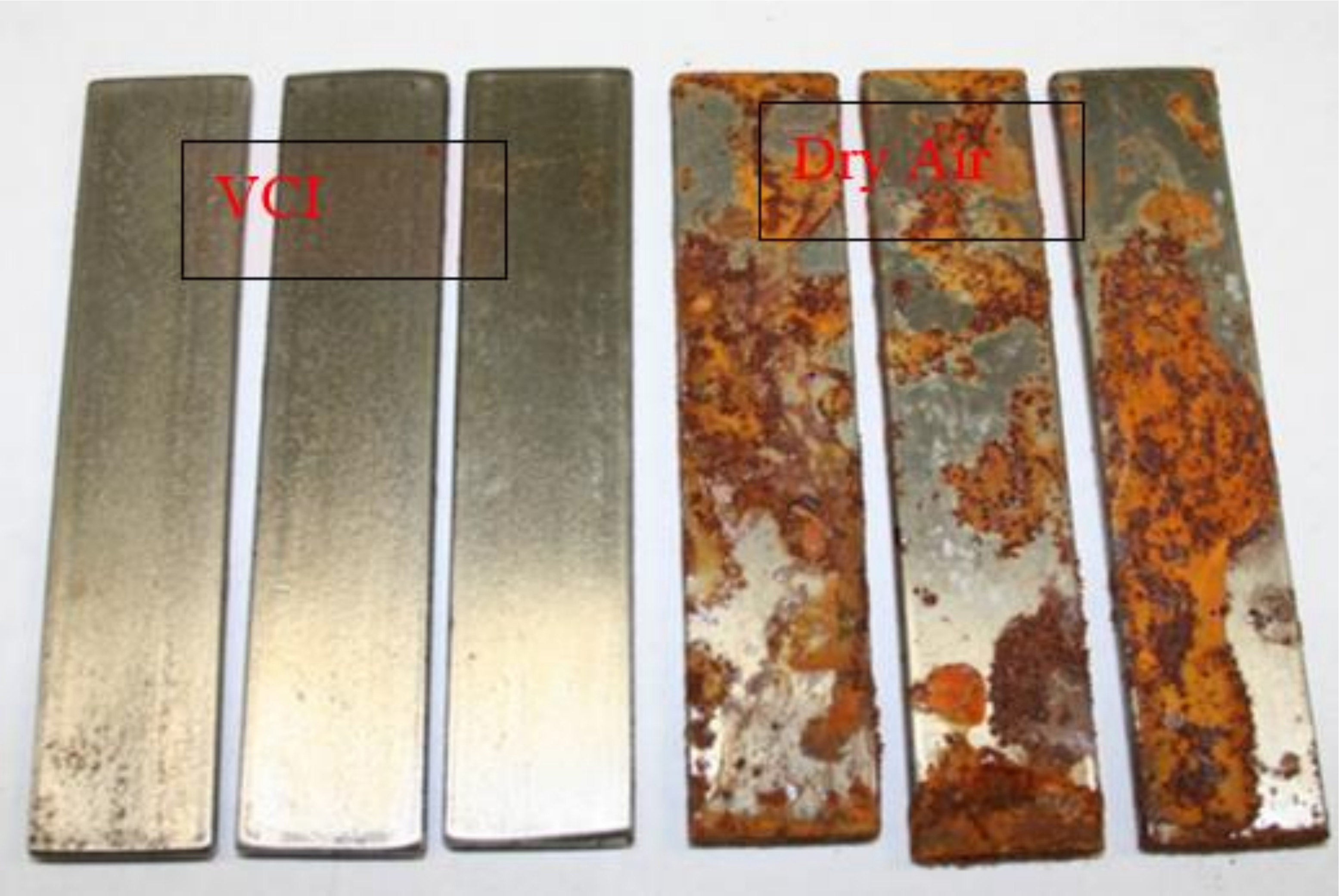
Comparison of Dry Air and VCI+ Dry Air Dry, Day 120



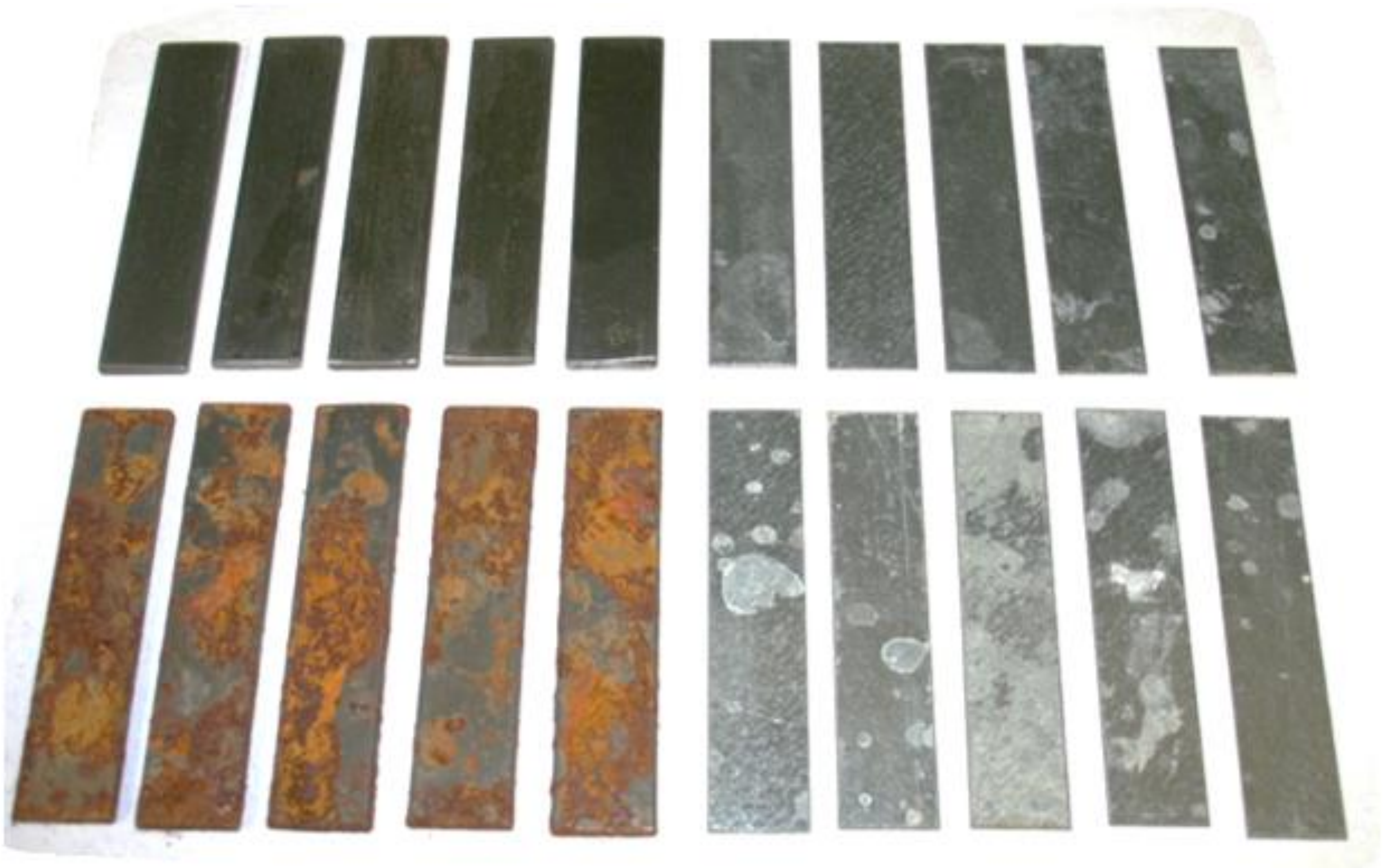
Galvanized steel , Day 120



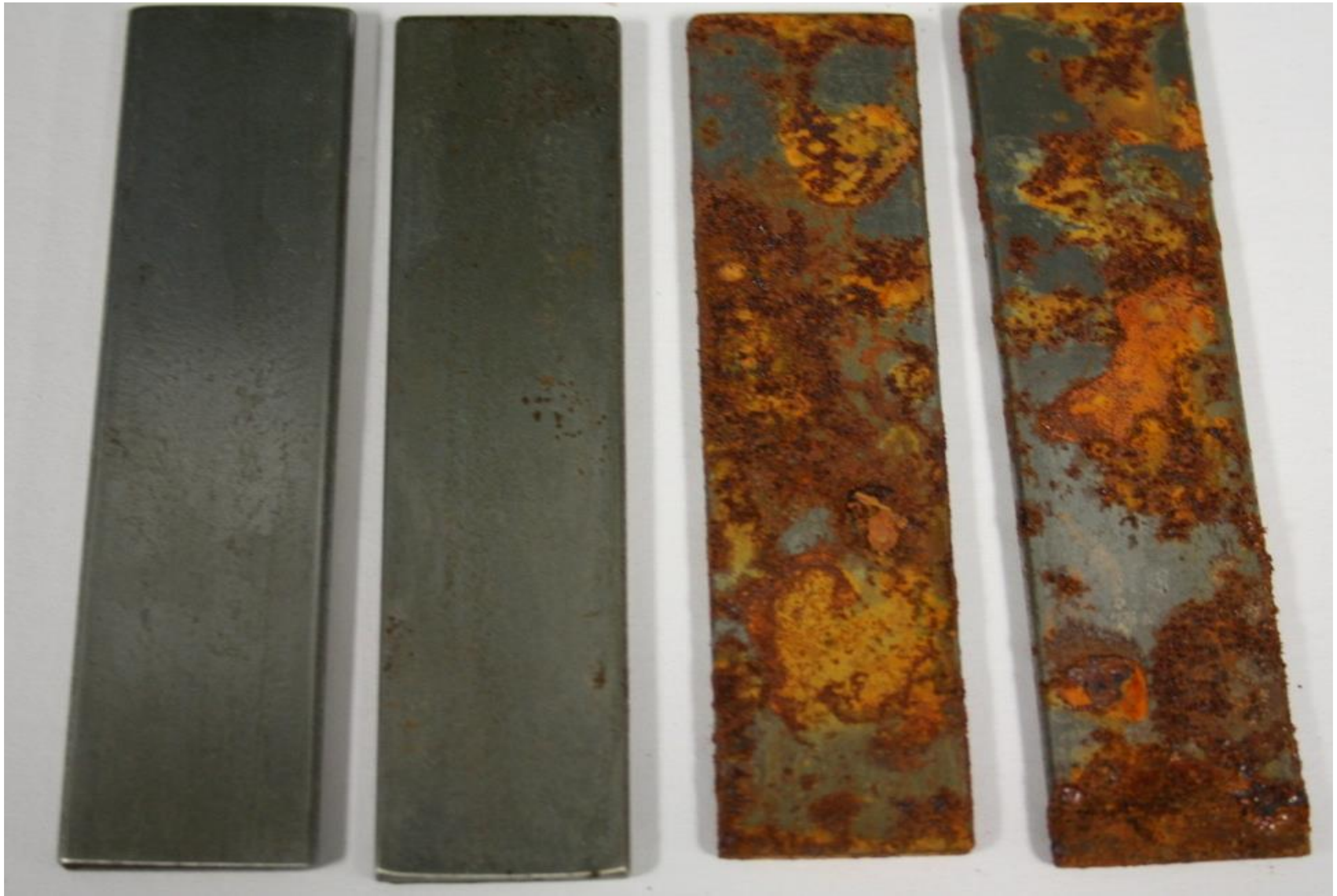
Comparison of surface condition of carbon steel samples in Dry Air and VCI+ Dry Air Dry, 3,720 hours (155 days)



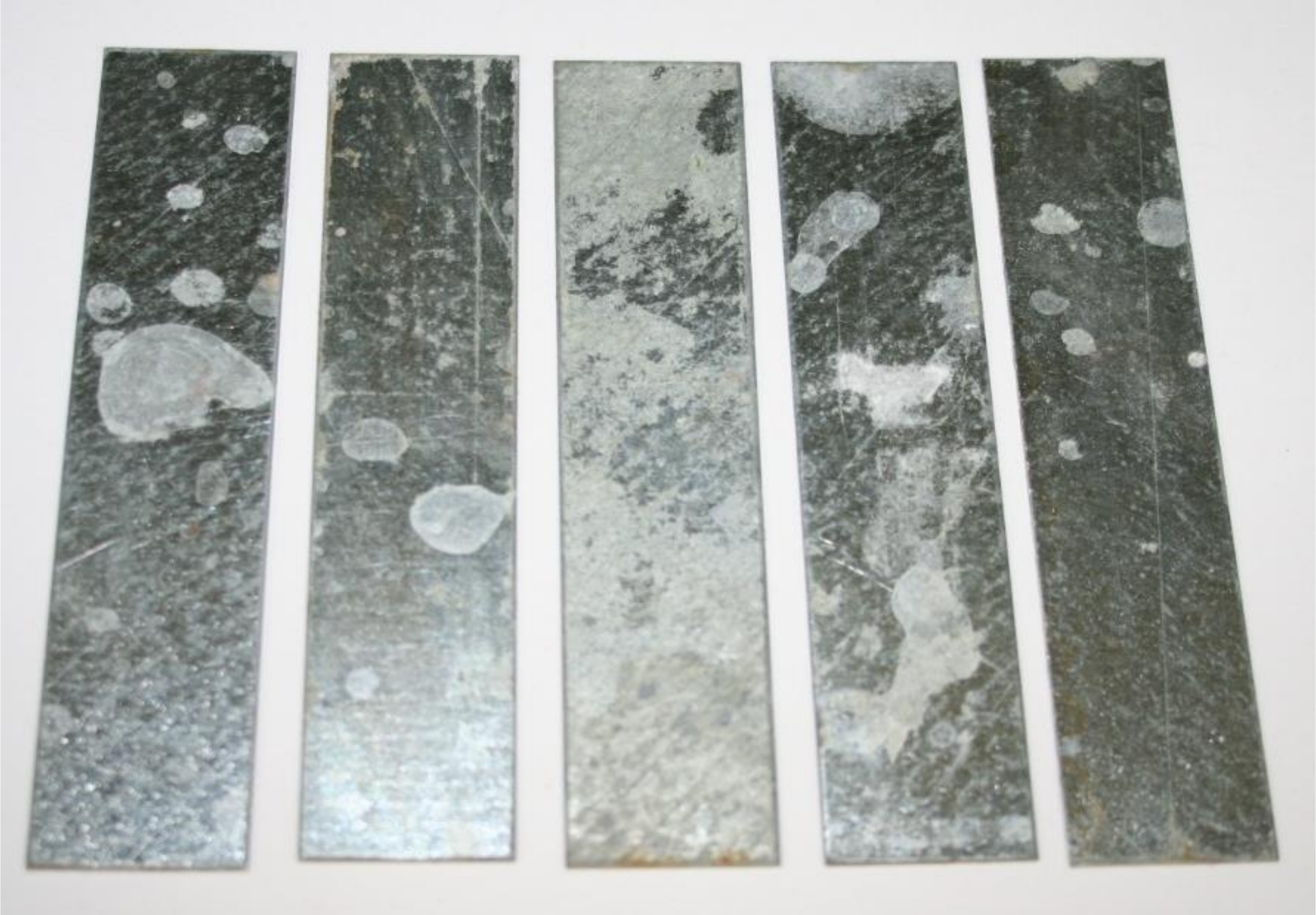
Comparison of Dry Air and VCI+ Dry Air Dry, 4,464 hours (186 days)



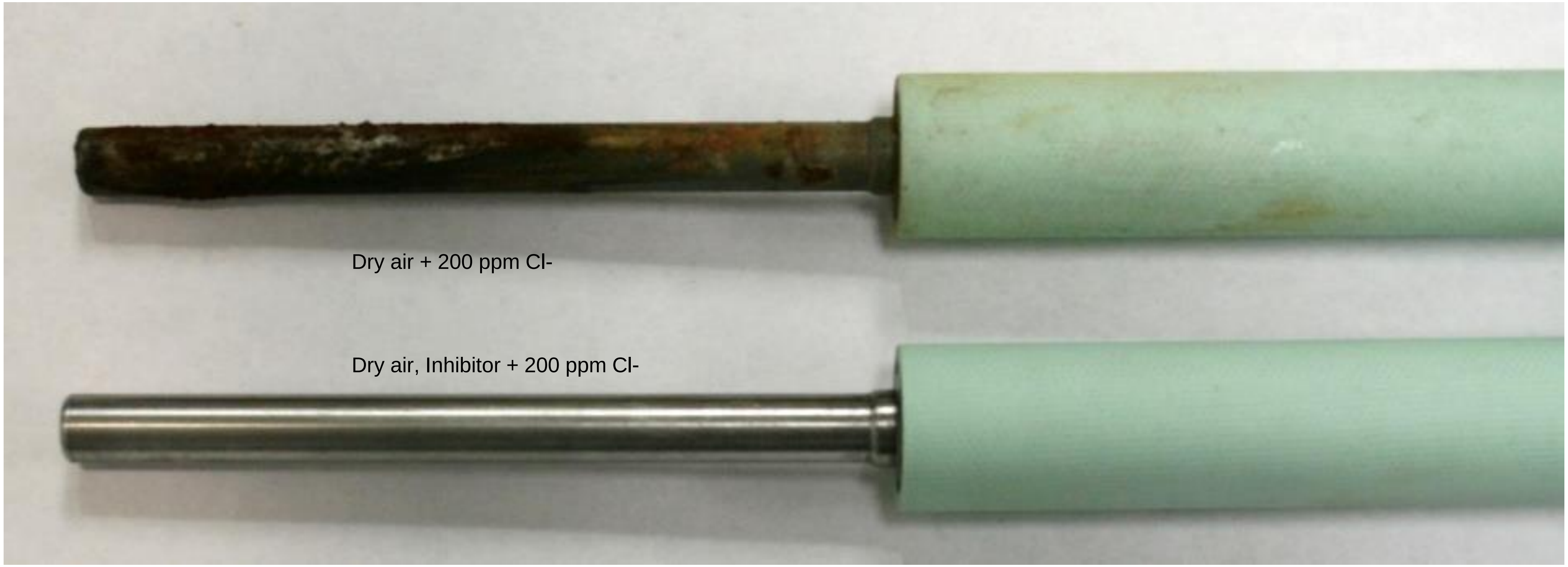
Comparison of surface condition of carbon steel samples in Dry Air and VCI+ Dry Air Dry, 4,464 hours (185 days)



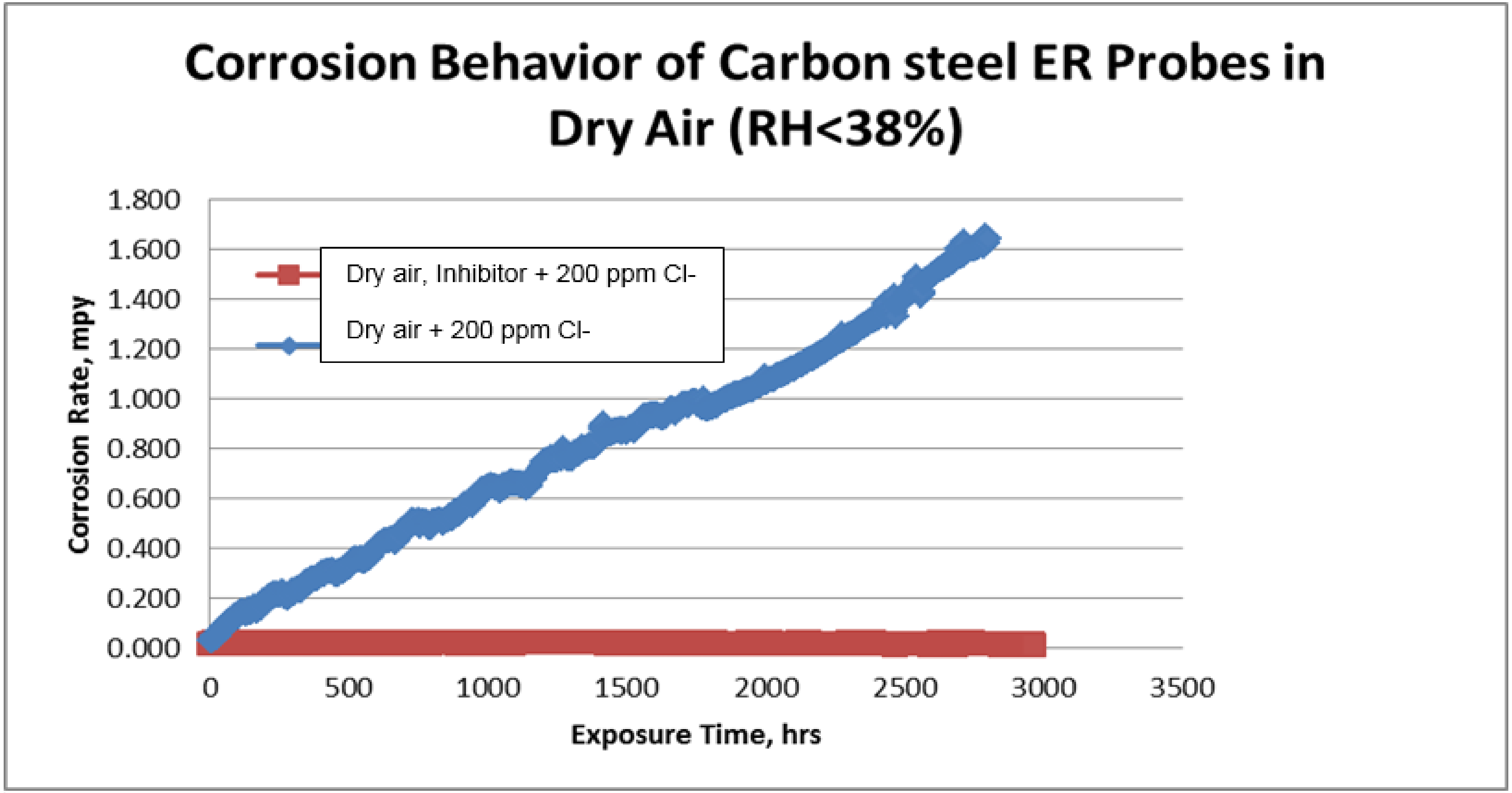
Surface condition of galvanized steel samples in Dry Air after 4,464 hours (185 days)



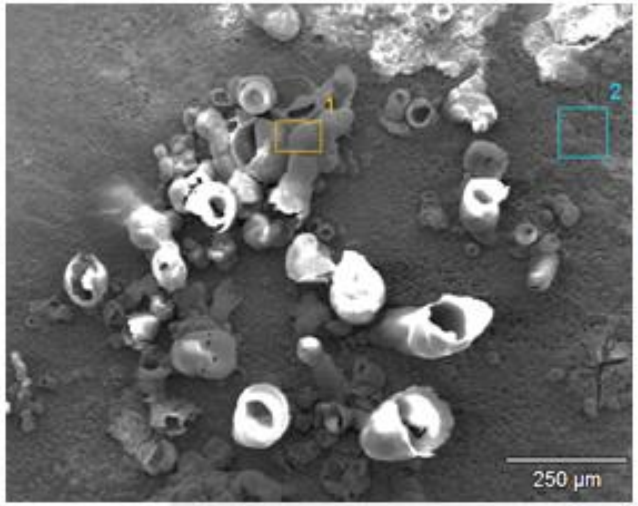
ER probes after 4,464 hours (185 days) exposure, top probe exposed to dry air, lower probe protected with inhibitor.

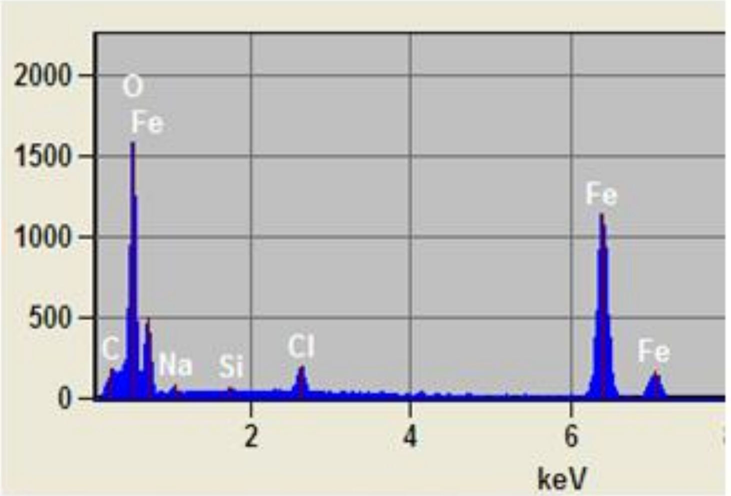


Corrosion Rate using ER Probes



SEM/EDAX analysis on the steel sample in dry air test chamber after 186 days, showing severe rust formation

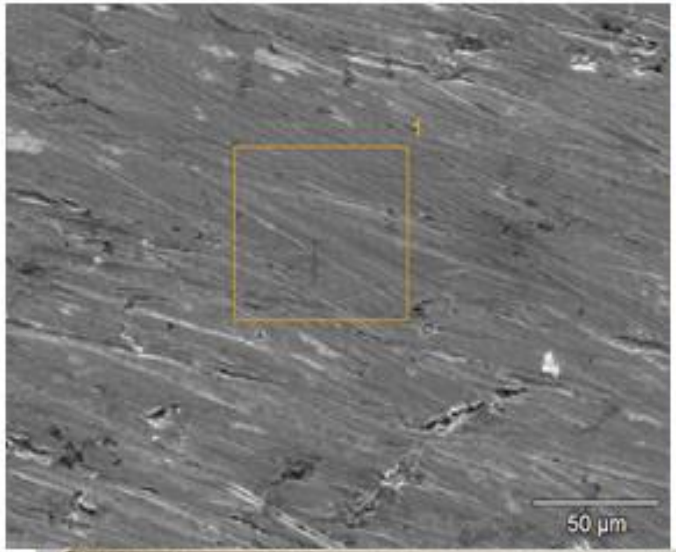


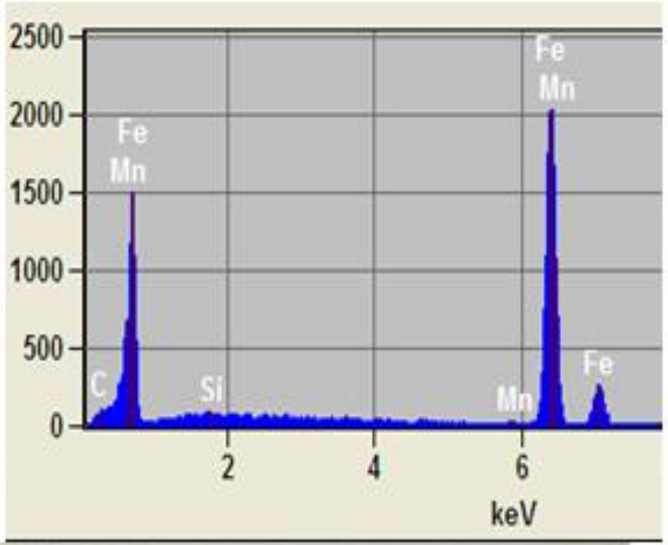


Weight %

	C-K	O-K	Na-K	Cl-K	Fe-K
steel dry air (1)_pt1	5.35	30.01	1.77	0.24	62.63
steel dry air (1)_pt2	6.04	26.35	1.69	0.43	65.50

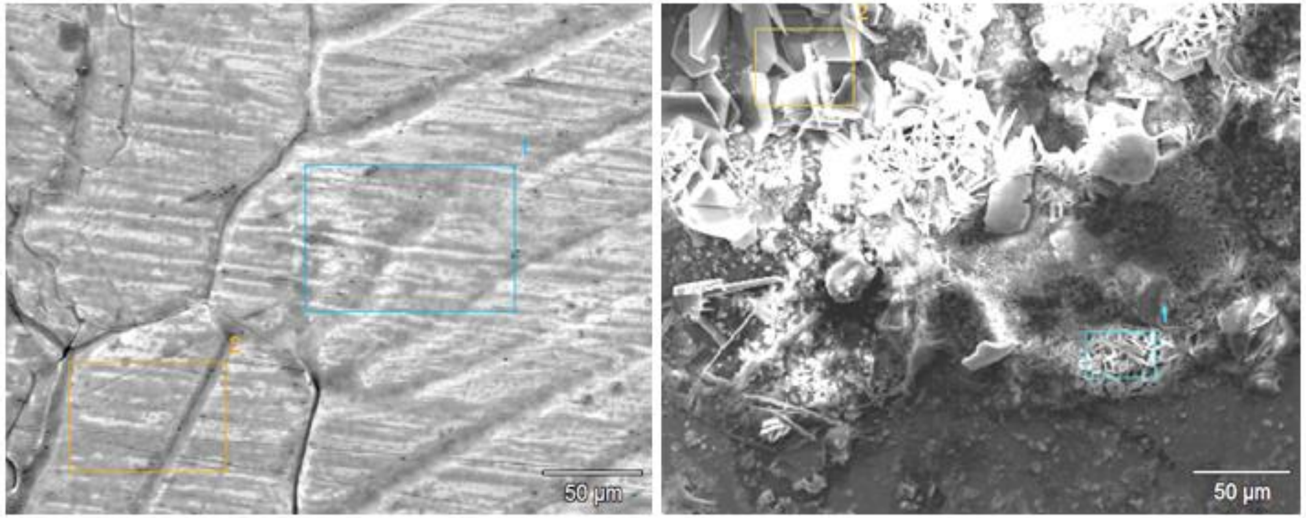
SEM/EDAX analysis on the steel sample in dry air + VCI test chamber after 186 days (4,464 hrs), showing corrosion free surfaces.

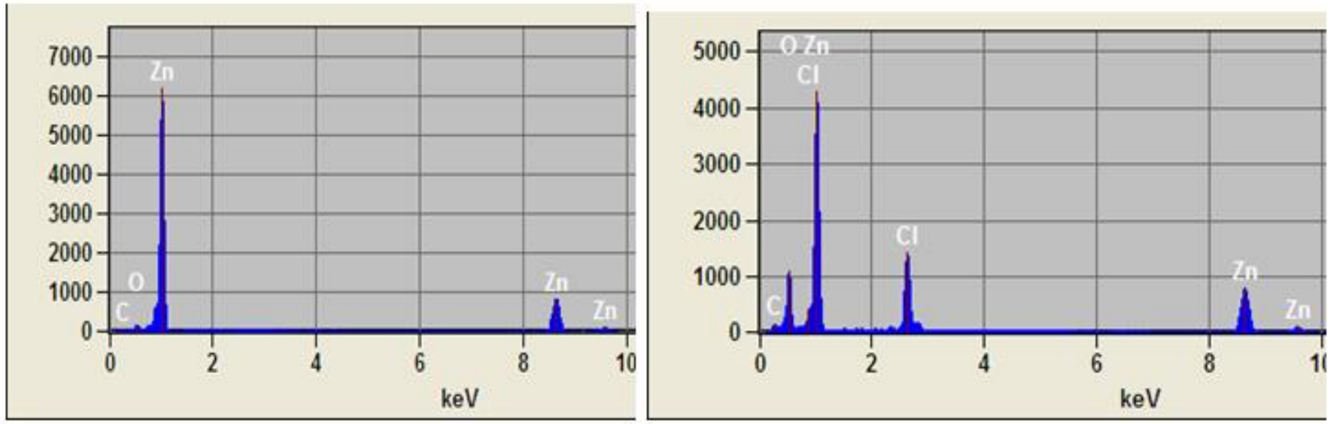




Weight %

	C-K	Si-K	Mn-K	Fe-K
steel dry vci(1)_pt1	4.40	0.40	0.57	94.63





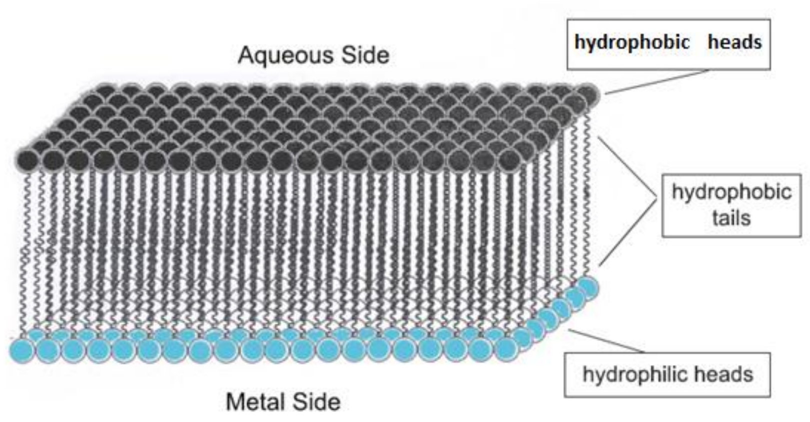
Weight %

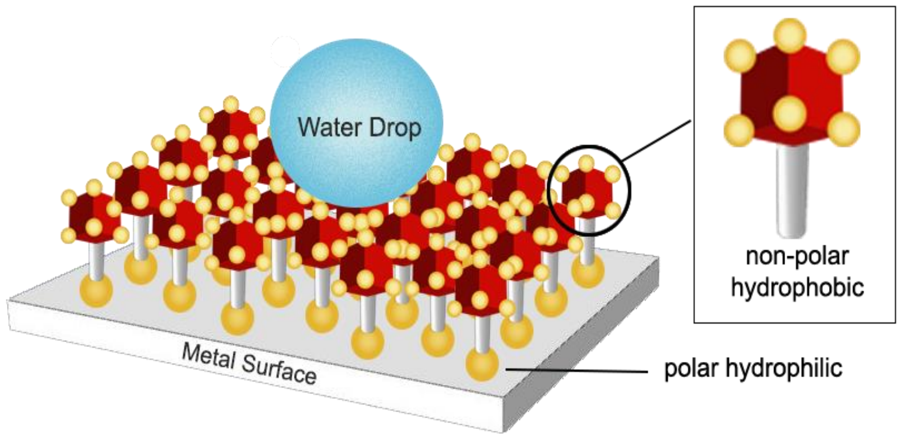
	C-K	O-K	Cl-K	Zn-K
gal dry(2)_pt1	4.05	20.07	13.61	62.27
gal vci(2)_pt2	10.28	3.12		86.59

SEM/EDAX analysis on the galvanized steel samples in dry air with and without VCI addition after 186 days, showing only white rust formation on dry air exposed

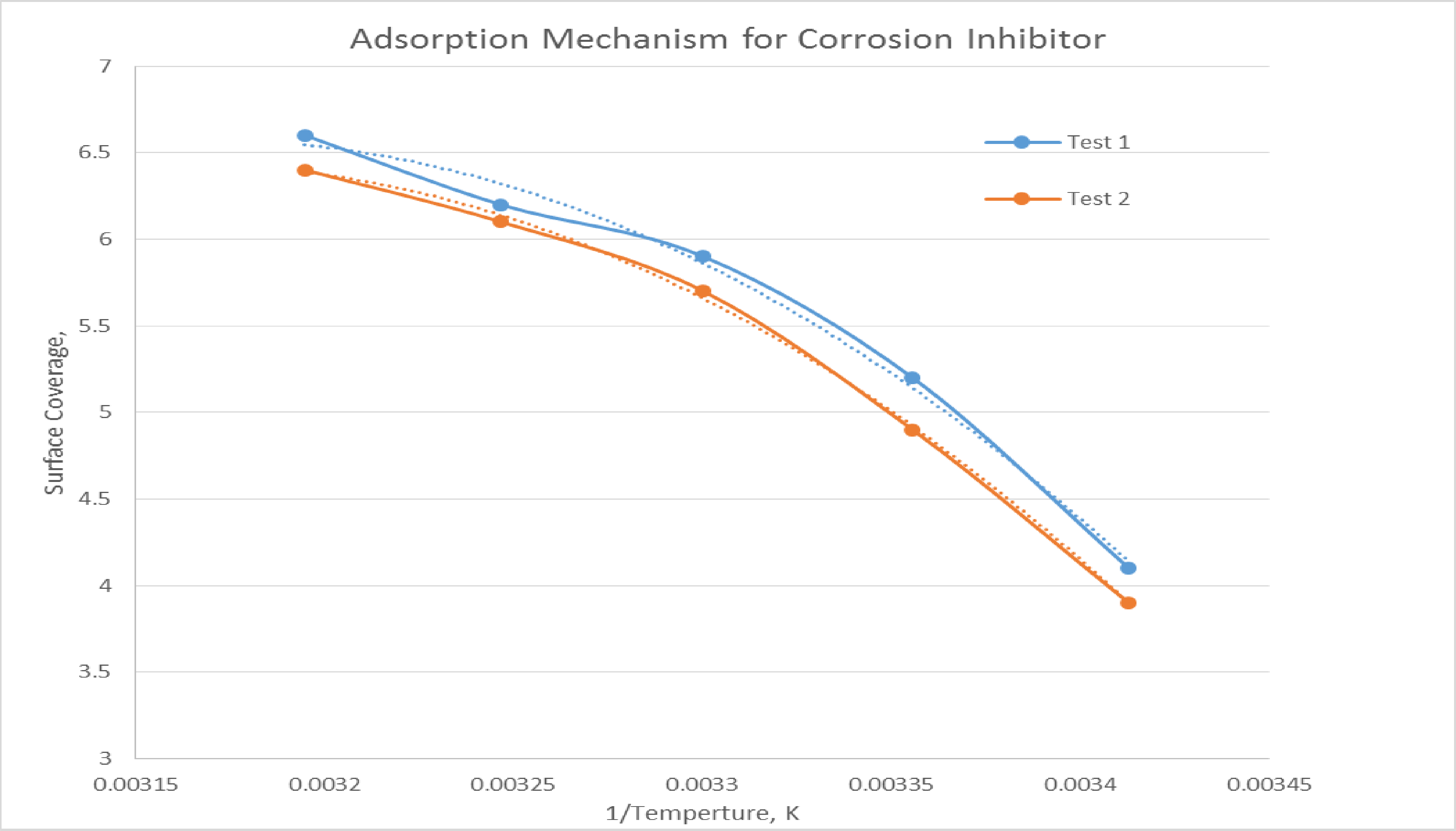
How VCI works?

- VCI use compounds that work by forming a monomolecular film between the metal and the water. In Film Forming Inhibitors, one end of the molecule is hydrophilic and the other hydrophobic.





Langmuir adsorption isotherm showing the relationship between surface coverage and temperature for VCI Inhibitor on the surface of steel. Adsorption Energy for the VCI inhibitor was roughly -10 to -14 kJ/mol, indicative of an inhibitor with strong physical adsorption to the metal surface



Conclusions

- Test results have demonstrated that corrosion inhibitors have superior advantages over the dry air system.
- ER probes showed a corrosion rate of 0.04-0.08 mpy for VCI treated while the dry air samples showed a 1.3-1.6 mpy corrosion rate and ER probes were heavily corroded.
- Samples that were exposed to dry air showed corrosion attack and red rust formation after 21 days of exposure.
- The dry air exposed samples showed an increasing trend, indicating inability of controlled humidity protection to retard corrosion once corrosion reaction had started. Indicating that a dry air system is not an effective method to retard corrosion.

- Electrochemical polarization behavior showed the addition of VCI to the environment expands the region of stability of passive film. The passive film breakdown potential for VCI treated steel samples increased by nearly 1.0 volt, indicating less susceptibility to localized corrosion.

- The advantage of the VCI inhibitor is the creation of a strong physisorption to the steel surface that minimizes any surface contact with corrosive species due to its hydrophobic film. Therefore, have superior advantages over the dry air or gas blanketing system in the presence of aggressive environments that contain excessive salt, oxygen and moisture.

Summary:

The VCI addition provide effective corrosion protection for steel materials exposed to the environment for short term storage.

in theory, controlled humidity protection systems can suppress the cathodic reaction and lower the corrosion rate, in reality the amount of moisture and oxygen that is required to initiate the corrosion reaction for steel is still extremely low. A dry air controlled humidity system can reduce the moisture level, but it won’t be enough to prevent corrosion and the steel sample will corrode. Furthermore, once corrosion begins, the dry air system cannot retard the accelerating corrosion reaction.