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Mineral wool CUI mitigation improvements

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ABSTRACT

Mineral wool has been used for well over half a century as insulation to reduce heat loss, provide personnel protection, and protect against hearing loss. Corrosion under insulation (CUI) has been a major topic of interest as process facilities age and experience issues with corrosion, particularly on pipelines. Efforts have focused on reducing any effect of the insulation material on corrosion – e.g., by reducing chlorides, making the insulation hydrophobic, and recently, by upgrading the hydrophobic performance in terms of high-temperature resistance. The next step is to introduce a proprietary corrosion inhibitor within the mineral wool. If water does make its way to the metal substrate, the inhibitor will activate in contact with water to mitigate corrosion.

This paper will present the CUI-mitigating efficacy of mineral wool with an integral corrosion inhibitor using the ASTM C1617 test modified for various chloride concentrations above the standard. The paper also discusses corrosion-inhibiting mechanisms, particularly how such mechanisms can modify the environment around steel substrates to mitigate factors that advance stress corrosion cracking.

Key words: CUI, Mineral Wool, Inhibitors, ASTM C1617, SCC (Stress Corrosion Cracking)

INTRODUCTION

For decades, corrosion under insulation (CUI) has plagued owners and operators in process-heavy industries like petroleum refining and petrochemicals. The ingress and migration of water through the insulation and onto the metal surfaces of piping, vessels, and other plant equipment can lead to corrosive attack that causes leakages or ruptures, process stoppages, or even a shutdown of an entire plant to make repairs. A CUI event can negatively impact the plant's health, safety, and environmental (HSE) metrics and damage the company's reputation.

There is no one-size-fits-all solution for CUI because there is no singular type of CUI. Each owner has slightly different process complexities that make their CUI situation unique. Mitigating CUI is often a system challenge requiring a multi-layered approach.

Regardless of the unique complexities, general CUI shares three main ingredients: unprotected metal, water, and air. The first ingredient to address would be to protect the metal surface. Various coating types, such as epoxy and TSA, have had success at mitigating CUI. However, successfully applying and maintaining a perfect coating for the operating lifetime of the equipment is a difficult task. Eventually, water will find its way through imperfections, or holidays, in the coating and reach the metal surface to preferentially attack and corrode those weak spots.

Water is the next ingredient to address in mitigating CUI. Water is an essential medium for corrosion—remove the water and the corrosion stops. Mineral wool insulation products, which have a long history of effective thermal and acoustic insulating performance, have recently been treated with water-repellent additives. Such additives have a proven ability to shed water from the insulation, helping to reduce the time that insulation stays wet. In extensive testing, the additives made the insulation five times more water-repellent (at 482 °F/ 250 °C) than standard EN-compliant stone wool, even after heating and aging. [1]

Because the mineral wool insulation is an open-cell material, it allows a path for water to escape through evaporation. This bodes well for reducing the time of wetness of the insulation. A reduced wetness time translates to lower corrosion rates and longer operating life between repairs or replacements.

Just like coatings, water-repellent insulation can have weak spots, joints, or gaps where water can enter and migrate to the metal surface. In those cases, another layer of defense is useful to mitigate corrosion. A new corrosion inhibitor additive technology was recently developed to impart the mineral wool insulation with a water-repellent coating and CUI mitigating inhibitor in one package.

Applied to the mineral wool during manufacture, the corrosion inhibitor enters the leachate water as it migrates through the insulation. The inhibitor activates on contact with water to coat the metal with a thin protective film and help neutralize the corrosive agents brought in by the water. The novel corrosion inhibitor additive in mineral wool has been tested to mitigate both general CUI and stress corrosion cracking (SCC)—a corrosion failure phenomenon more common in buried carbon steel installation. More recently, SCC has been found on above-ground uncoated carbon steel piping. The resulting cracks and leaks generated by SCC require taking the pipe out of service to perform time-consuming and costly repairs.

A series of laboratory tests were commissioned to confirm the inhibitor-treated insulation's effectiveness at mitigating corrosion in various scenarios:

1) Test the performance against known corrosive agents such as chlorides with small-scale coupons.
2) Test for stress corrosion cracking mitigation.

EXPERIMENTAL PROCEDURE

PART 1: Corrosion testing to ASTM C 1617 in the presence of chlorides

The test method used for performance testing in the presence of chlorides, a form of corrosion accelerant, was the ASTM C1617-19 Standard Practice for Quantitative Accelerated Laboratory Evaluation of Extraction Solutions Containing Ions Leached from Thermal Insulation on Aqueous Corrosion of Metals. [2] This test method measures the relative corrosion rates of steel in contact with solutions extracted from thermal insulation in reference to plain distilled water and other solutions.

To obtain the extracted solution for ASTM C1617 testing, the standard test procedure ASTM C871 Standard Test Methods for Chemical Analysis of Thermal Insulation Materials for Leachable Chloride, Fluoride, Silicate, and Sodium Ions was used. [3] This procedure works by mixing ground-up pieces of thermal insulation with boiling water. This mixture is filtered to remove any solids, and the solution is then dripped onto a heated rectangular steel coupon over four days. A short PVC pipe adhered onto the steel coupon in order to contain the solution. The weight of the steel coupon is measured before and after the test period; subsequently, a corrosion rate year is calculated in mils per year (MPY). The test aims to mimic the corrosive environment that steel might see under insulation on a small scale. The main ingredients for corrosion are present: unprotected metal, oxygen, water, and a catalyst such as heat.

This test is done alongside a control. In this case, a solution of distilled water (0 ppm chloride) is evaluated along with a 1 ppm and a 5 ppm chloride solution.

The test method can also be altered to compare the mass loss corrosion rate of the extracted solution from thermal insulation with additional chloride concentration included. Chlorides are well-known corrosion catalysts, as mentioned in NACE SP 0198-2017 Control of Corrosion Under Thermal Insulation and Fireproofing Materials – A Systematic Approach, these tests are performed to determine what effect increased chlorides might have in insulation with and without corrosion inhibitors. [4]

The testing compared mineral wool with corrosion inhibitors to other insulation types such as calcium silicate, expanded perlite, and aerogel. All solutions from thermal insulation were dosed with 100 ppm Cl, 300 ppm Cl, and 600 ppm Cl. The 600 ppm Cl was used as the upper limit, as this level of chlorides would not be acceptable per the ASTM C795 standard for stainless steel. [5]

PART 2: Stress corrosion cracking testing

Mineral wool containing corrosion inhibitors has demonstrated positive benefits for mitigating steel surface corrosion, but what about SCC? Several research papers have been published on the phenomenon of SCC on uncoated above-ground steel pipelines under insulation. The following tests were conducted using the same test standards in these research papers, with particular focus on testing method proposed by Kevin Ralston et al. [6, 7] The types of testing presented in this paper do not depict the full scale physical representations of piping out in the field. The tests discussed are laboratory simulations using similar chemistry experienced in the field and do not take into account the physical contact between the insulation and metallic substrate. Research on SCC of carbon steel under thermal insulation is ongoing as the phenomenon is relatively new.

To first simulate aging effects, unused "out-of-the-box" mineral wool with corrosion inhibitors was heat-aged in a laboratory oven for 45 days at 302 °F (150°C). A cross-sectional sample of the heat-aged pipe section was tested by two different methods. The first, cyclic potentiodynamic polarization (CPP), was based on ASTM G61 Standard Test Method for conducting cyclic potentiodynamic polarization measurements for localized corrosion susceptibility of Iron-, Nickel-, or cobalt-based alloys. [8] The second was slow strain rate (SSR) testing to ASTM G129 Standard Practice for Slow Strain Rate

Testing to Evaluate the Susceptibility of Metallic Materials to Environmentally Assisted Cracking. [9] Both test methods are standard in the study of SCC of underground steel. These test methods were used to study the cracking susceptibility of CSA Z245.1 Gr 359 CAT II SS pipe steel, which is exposed to aqueous solutions extracted from mineral wool insulation.

Insulation solution extraction

Heat-aged mineral wool with corrosion inhibitors was shredded, mixed in a blender with deionized water, and boiled for 30 minutes, per the ASTM C871 standard. The test procedure was modified from the standard in two ways. First, the insulation was not dried in an oven, based on previous experience of having little impact on weight in previous tests. And second, the extracted insulation solution was distilled to 1/5 the original volume in order to simulate a cyclic wet-to-dry scenario typically experienced on a pipeline. This concentration may not be an exact match to those experienced in the field, however the species being extracted would be the same as the ones being exposed to the metal pipe.

Cyclic Potentiodynamic Polarization (CPP)

CPP testing generally indicates stress corrosion cracking susceptibility, more specifically, an active-passive nose in a CPP curve. However, SCC can also occur without the presence of an active-passive nose. And conversely, cracking may not occur even with an active-passive nose present. CPP testing was done using the ASTM G61 (Standard Test Method for Conducting Cyclic Potentiodynamic Polarization Measurements for Localized Corrosion Susceptibility of Iron, Nickel, or Cobalt Based Alloys) as well as some standard operating procedures based on the lab’s experience.

The following test parameters were implemented.

- Test temperature: 125°C (257°F)
- Open circuit potential (OCP) measured for approx. 2 hrs while N_2 bubbled through insulation-extracted solution at room temperature and was monitored overnight at test temperature and pressure
- Tests initiated at -0.05V vs. OCP and scanned at more positive potentials
- The scan was reversed once the current density reached 1 mA/cm^2
- Scan Rate: 0.167 mV/s

Slow Strain Rate Testing (SSR)

Slow Strain Rate testing was performed similar to the ASTM G129 (Standard Practice for Slow Strain Rate Testing to Evaluate the Susceptibility of Metallic Materials to Environmentally Assisted Cracking) and standard operating procedures based on the lab’s experience. This test involves placing a small cylindrical carbon steel specimen under tension in a heated environment and submerged in solution extracted from insulation. The environment is simulated using an autoclave filled with extracted solution from insulation, the specimen is also connected to electrodes that polarize the sample to a desired hold potential (based on the CPP testing and within a range most likely to cause SCC). The specimen is slowly strained until failure, and the mode in which the specimen breaks is inspected for any evidence of SCC.

A control specimen, not exposed to any solution extracted from insulation, was also tested in a nitrogen-only environment to serve as a baseline.

SSR specimens were machined from CSA Z245.1 Gr. 359 CAT II line pipe steel, a popular steel type for pipelines used in oil and gas processing in Canada.

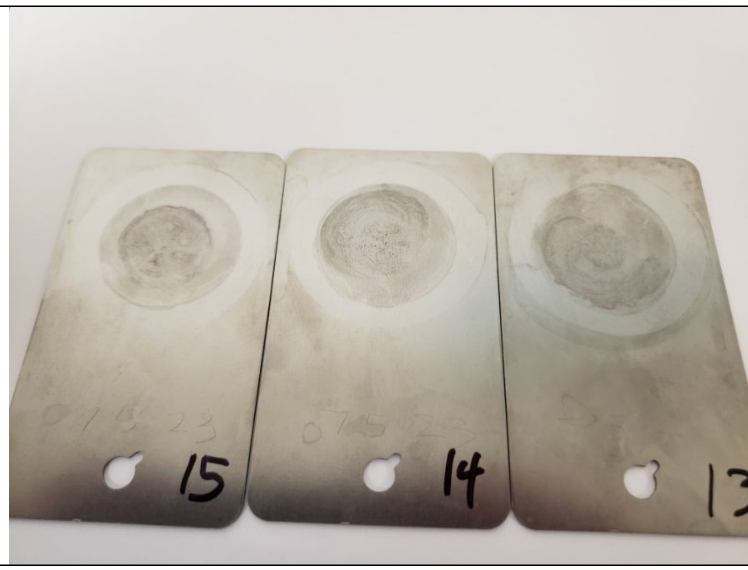
Fracture surface inspection was done using a scanning electron microscope (SEM). The surface was inspected for ductile failure or environmental cracking, which includes intergranular, transgranular quasi-cleavage, or mixed cracking.

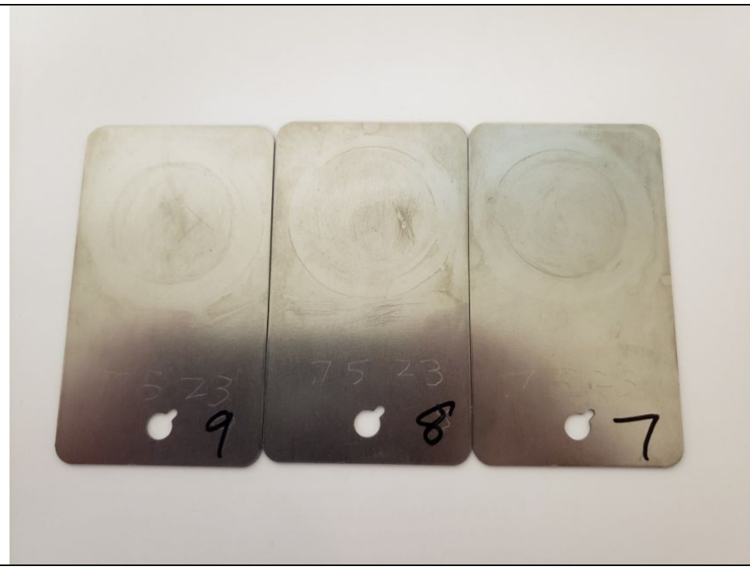
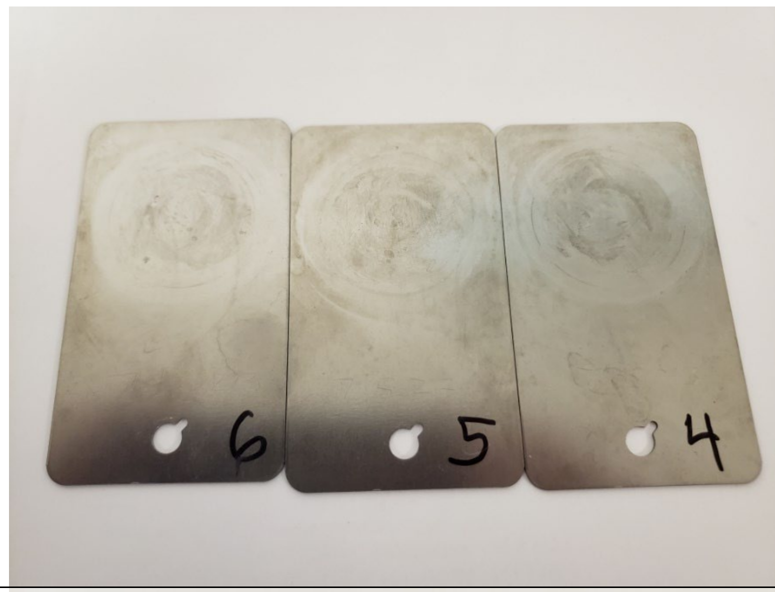
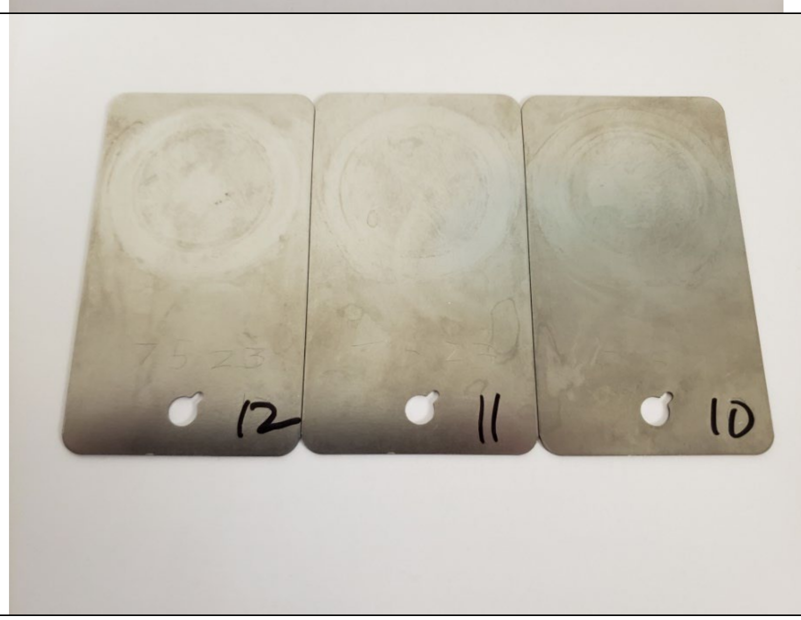
The following test parameters were implemented:

- Test temperature: 125°C (257°F)
- Autoclave filled with approx. 350 ml of insulation extracted solution with 150 ml vapor space
- Specimen was fully submerged in the area of failure
- Strain rate 1.3 x 10^-7 mm/s (5 x 10^-7 in/s)

RESULTS

PART 1: Corrosion testing to ASTM C 1617 in the presence of chlorides
Table 1: 100 ppm Chloride addition corrosion test with visuals of testing coupons

Solution	Average Mass loss corrosion rate (MPY)	Visual of coupon after cleaning
0 ppm	7.42	

Mineral wool with inhibitor +100ppm Cl	2.15	
Calcium silicate +100ppm Cl	2.04	
Expanded Perlite +100ppm Cl	2.62	

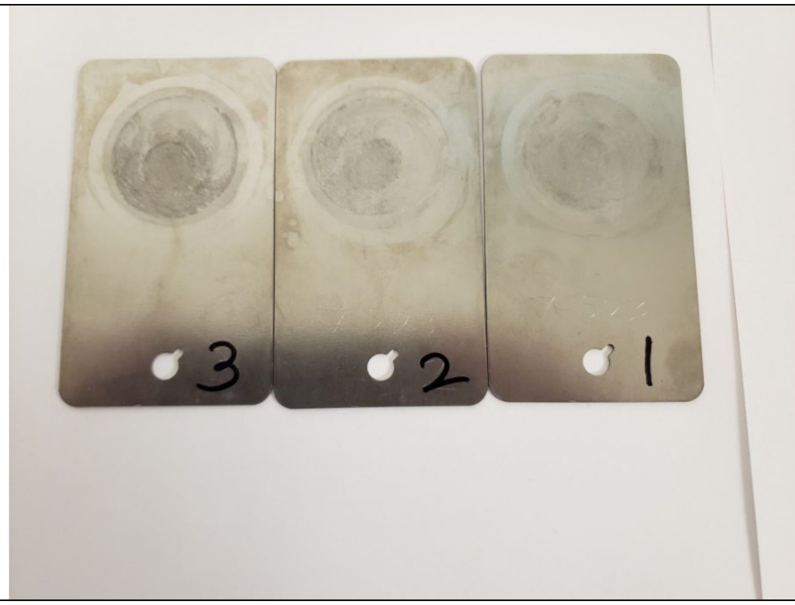
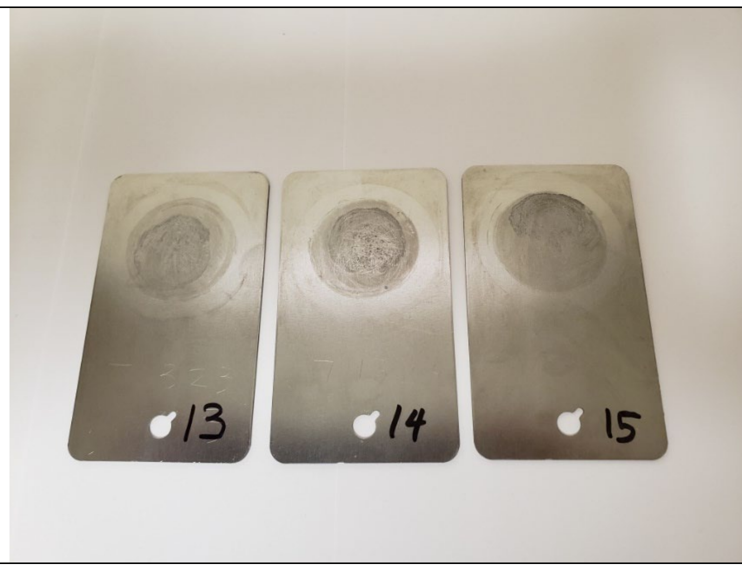
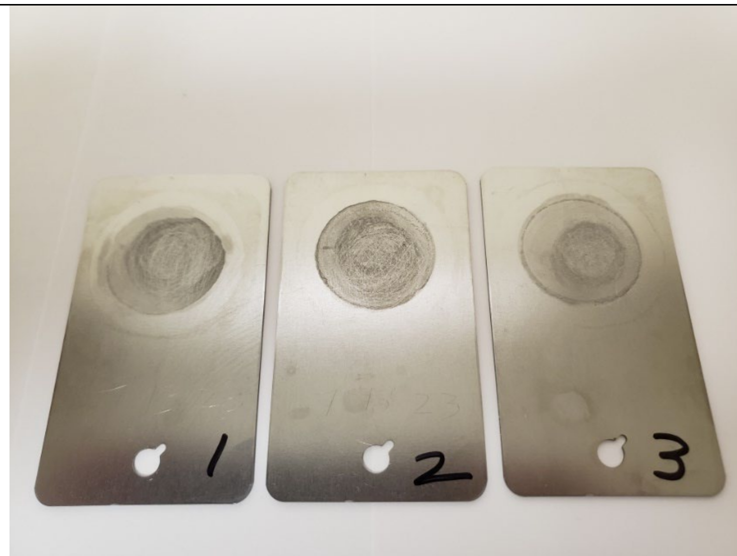
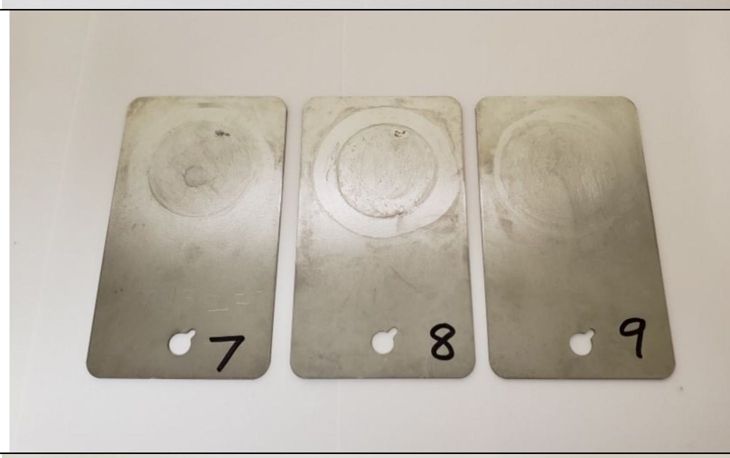
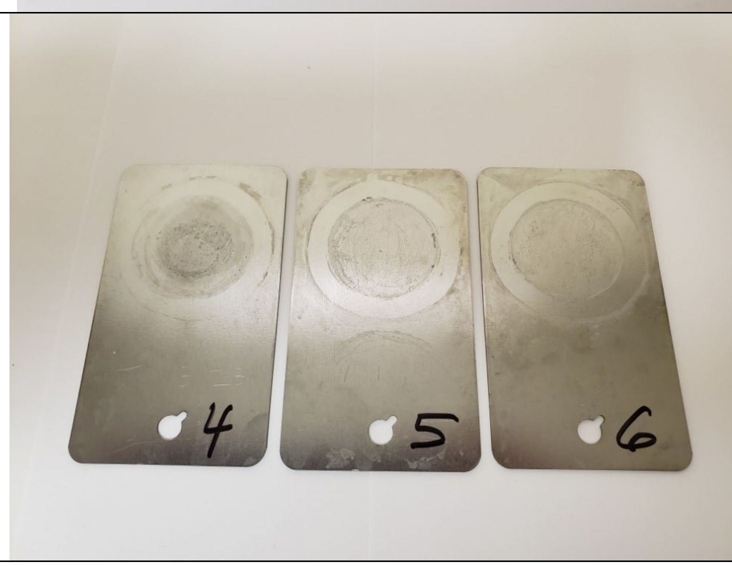
Aerogel+100ppm Cl	48.76	

Table 2: **300 ppm Chloride addition corrosion test with visuals of testing coupons**

Solution	**Average Mass loss corrosion rate (MPY)**	**Visual of coupon after cleaning**
0 ppm	8.06	

1 ppm	24.69	
Mineral wool with inhibitor +300ppm Cl	3.47	
Calcium silicate +300ppm Cl	7.38	

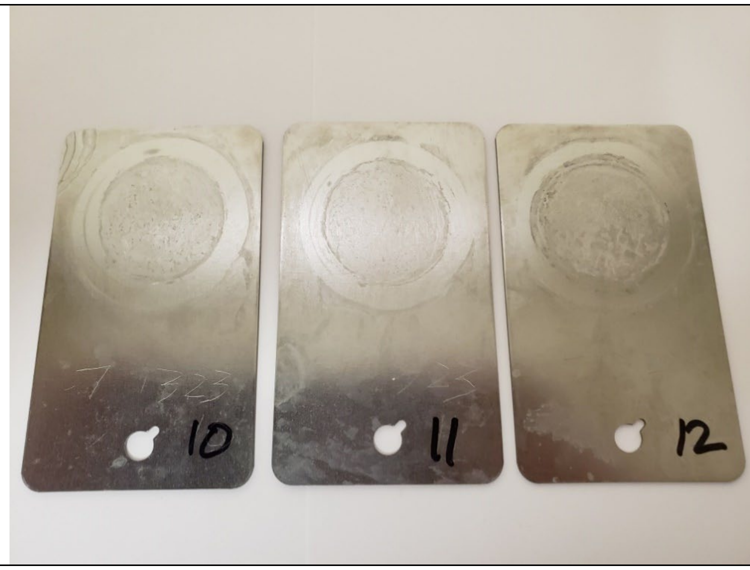
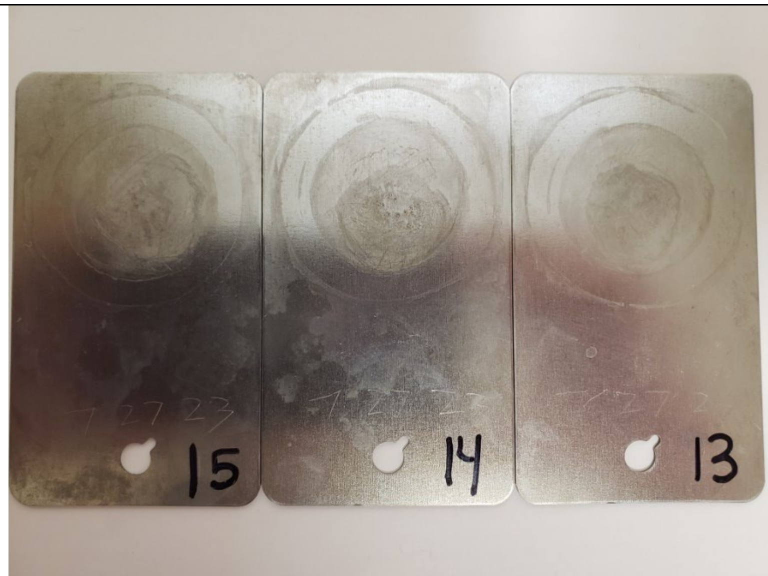
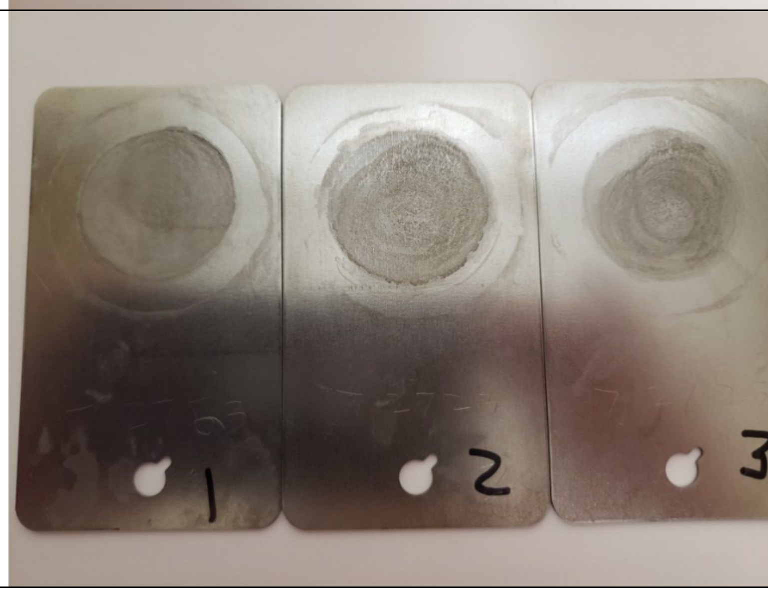
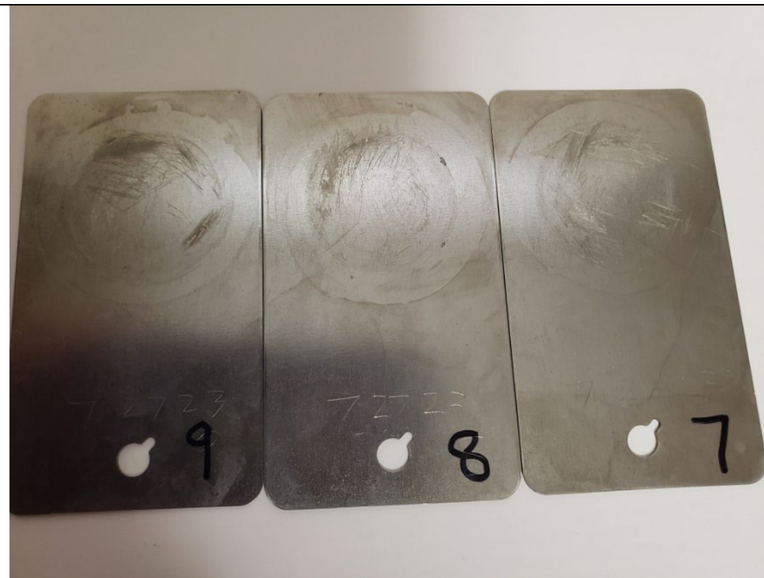
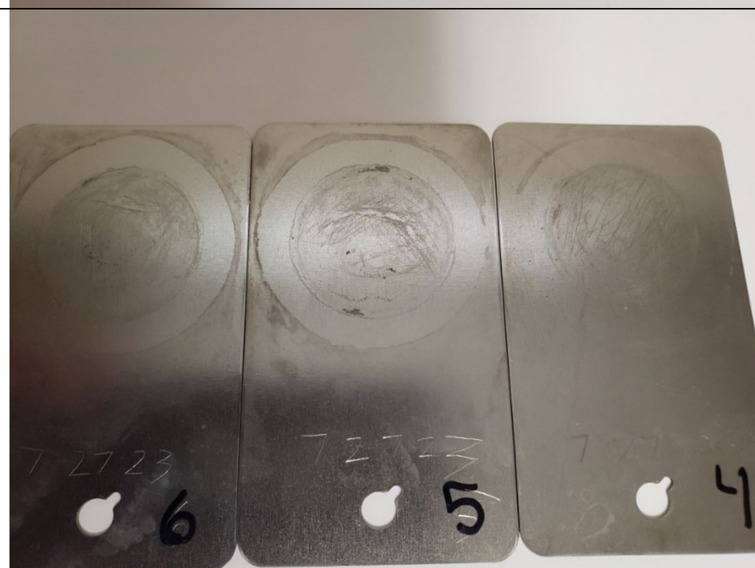
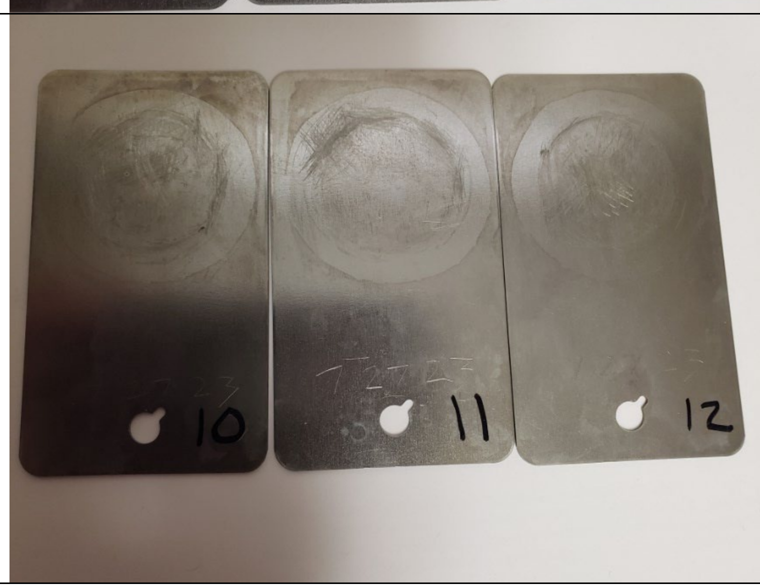
Expanded Perlite +300ppm Cl	6.74	

Table 3: 600 ppm Chloride addition corrosion test with visuals of testing coupons

Solution	Average Mass loss corrosion rate (MPY)	Visual of coupon after cleaning
0 ppm	6.17	
1 ppm	25.54	

Mineral wool with inhibitor +600ppm Cl	3.87	
Calcium silicate +600ppm Cl	2.72	
Expanded Perlite +600ppm Cl	3.00	

The results show that mineral wool with corrosion inhibitors actively protects the steel metal according to the ASTM C1617 test method with the addition of chlorides at concentrations up to 600 ppm. The metal coupons exposed to mineral wool with corrosion inhibitors plus 600 ppm chloride show a lower average mass loss corrosion rate at 3.87 MPY than the 0-ppm chloride reference solution at 6.17 MPY (as listed in Table 3). The results suggest that the extracted solution from mineral wool with inhibitors plus additional chlorides up to 600 ppm protects the metal and performs even better than the reference of distilled water (0 ppm chloride). The mineral wool with inhibitors performed to the same level as expanded perlite and calcium silicate, which may mean that they also have a substance that inhibits the corrosive effects of chlorides.

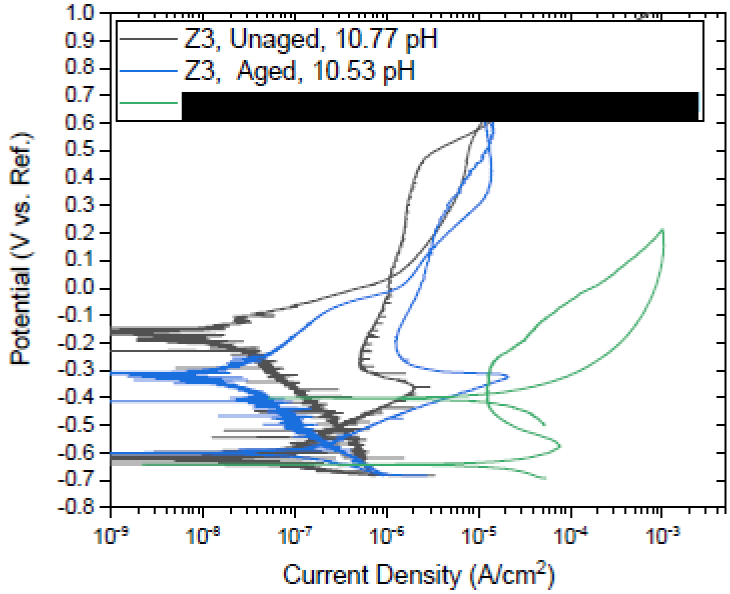
However, the aerogel material with 100 ppm chlorides does not perform to the same level as mineral wool with inhibitors, perlite, or calcium silicate. The corrosion level of aerogel with 100 ppm chlorides was in the 40+ MPY category, which puts it in the 5-ppm chlorides level according to ASTM C1617. There was a high probability of aggressive corrosion with aerogel that may lead to leaking under the PVC containers and subsequent contamination of adjacent samples—thus compromising the entire test. For this reason, aerogel was not included in the next higher levels of chloride tests up to 300 and 600 ppm chloride.

PART 2: Stress corrosion cracking testing

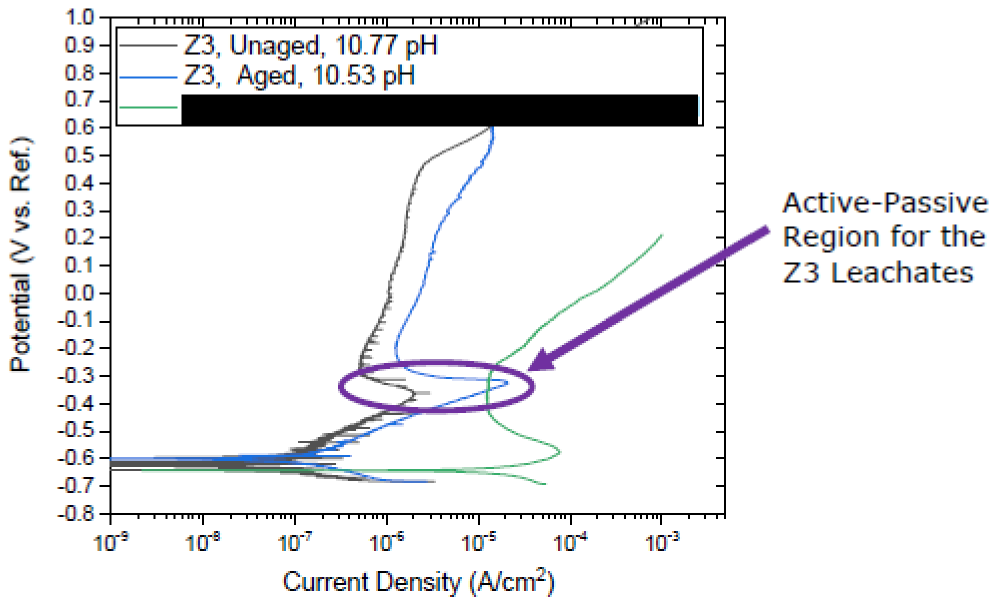
CPP testing with unaged mineral wool with inhibitors and heat-aged mineral wool with inhibitors both displayed an active passive region, as shown Figure 1. This suggests SCC is still possible.

As for the SSR testing with both unaged and heat-aged mineral wool with inhibitors, no cracking was observed (Table 4). The time-to-failure ratio remained close to 1, indicating only a slight reduction in strength. The fracture surface of the specimen shown in Figure 2 and 3 fails in a ductile manner and not through intergranular cracking. This paper does not include any control tests to show failure modes with intergranular cracking. For examples of specimens failing due to cracking using the same testing standards on various types of insulation other than mineral wool see white paper by Kevin Ralston et Al. [7]

Other studies with mineral wool without inhibitors have shown results indicating SCC especially when the pH dips below 9 after heat aging. [6, 7] With heat aging, the mineral wool with inhibitors did not decrease in pH, as shown in Figure 1. This indicates a chemical difference not seen before, which could help explain why the specimens did not crack when exposed to the extracted insulation solution.



(a)



(b)

Figure 1: (a) CPP curves and (b) the anodic polarization curves collected in concentrated insulation extract solution from heat-aged and non-heat-aged mineral wool treated with corrosion inhibitor labeled as (Z3).

Table 4: SSR summary of results performed on pipe steel specimens

Description	Time to Failure (Hrs)	Time to Failure Ratio* (Hrs)	Max Load (N)	Max Stress	Evidence of Cracking observed
Control (Nitrogen Test)	77.4	-	5611	95	No
Mineral wool with Inhibitors (unaged)	74.4	96.2	5216	88.3	No
Mineral wool with Inhibitors (heat aged)	75.3	97.2	5206	88.2	No

*Time to failure ratio = time to failure in environment/time to failure in air x 100

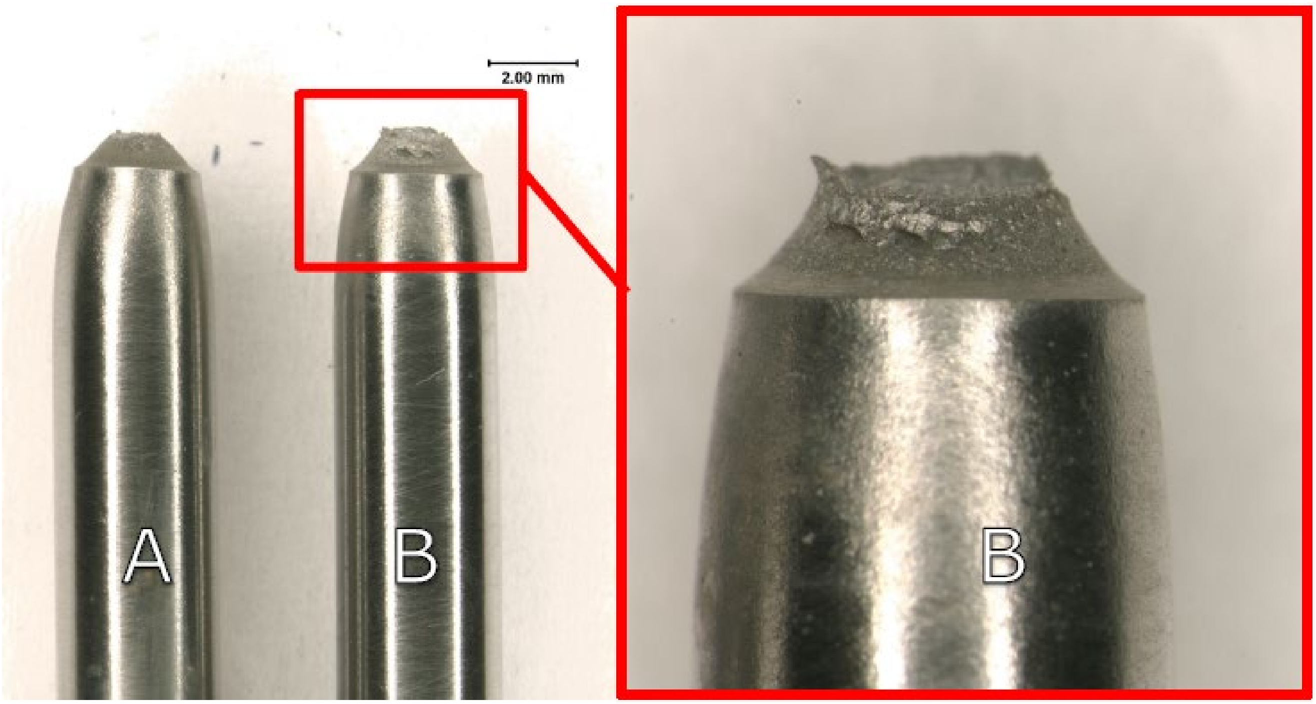


Figure 2: Stereo light photomicrographs of SSR specimen after testing at 257 °F (125 °C) in concentrated insulation extract solution from inhibited mineral wool (heat aged).

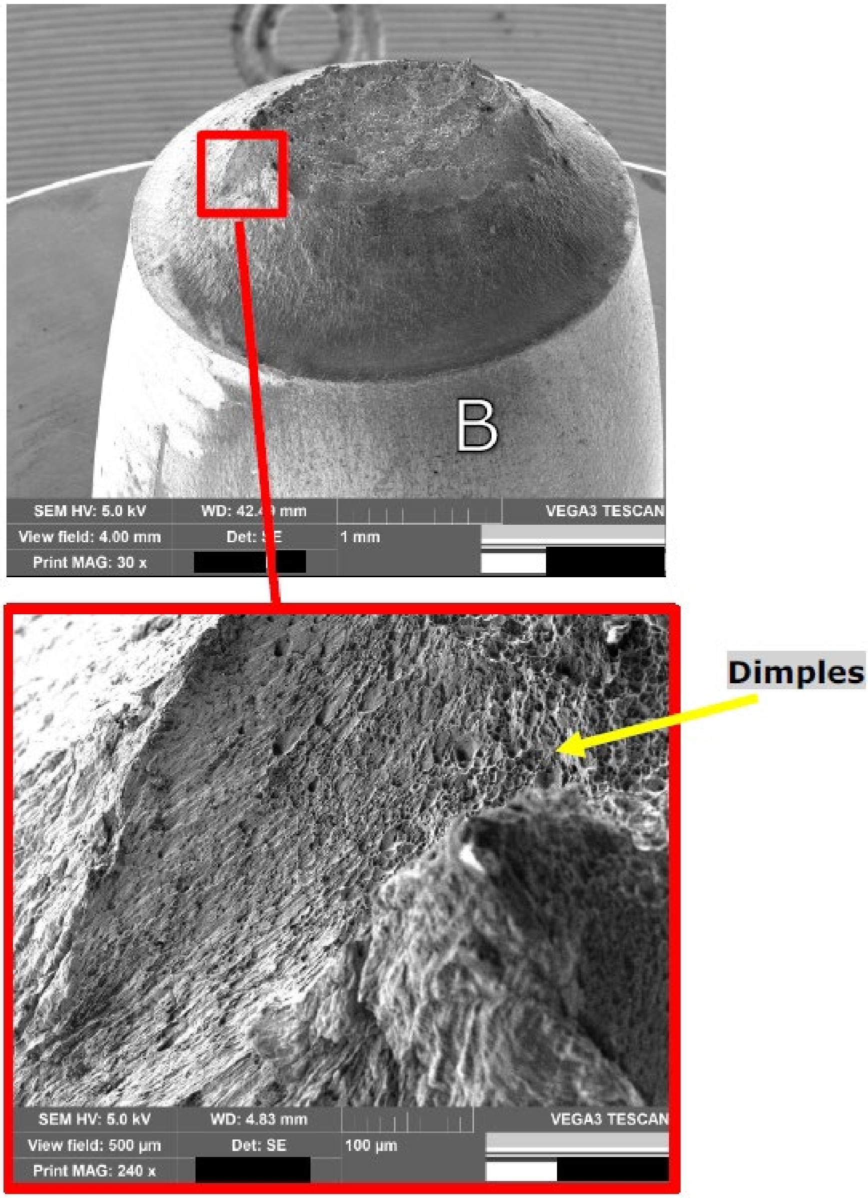


Figure 3: SEM images of test specimen after SSR specimen after testing at 257 °F (125 °C) in concentrated insulation extract solution from inhibited mineral wool (heat aged).

CONCLUSIONS

In testing to ASTM C1617, the mineral wool with inhibitors provides corrosion protection in a chloride-heavy CUI environment up to 600 ppm chlorides. This was not the case with other types of insulation materials that were tested. The mineral wool with inhibitors also showed no evidence of cracking when subjected to ASTM G 61 and G 129 testing for CPP and SCC. The pH of the extracted insulation solution after heat ageing for 45 days at 302 °F (150 °C) did not drop significantly from it’s unaged value.

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