



**FROM TRAUMA TO TRANSCENDENCE:
CORROSION UNDER INSULATION**

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ABSTRACT

Corrosion under insulation (CUI) is an insidious and costly problem that has bedeviled industry at large, and the protective coatings industry in particular. An overview of a coating journey is presented, one of trauma to transcendence, where inadequate coating performance of coating types two decades ago have now transcended into present day technologies and strategies that are extremely effective in addressing CUI.

Titanium Modified Inorganic Copolymer (TMIC) technology is described for both insulated and non-insulated applications systems, where TMIC is used in either a stand -alone mode or in conjunction with thermal spray aluminium (TSA).

Laboratory testing is outlined that compares and contrasts the anticorrosive and temperature resistance performance profiles of today's most advanced coatings engineered to combat CUI. Insulated pipe spools exposed to temperatures up to 400°C were exposed to laboratory controlled wet-dry cyclic regimes in order to mimic typical cyclic CUI in-service environments.

The impact of TMIC technology and its performance is evaluated from a risk management perspective to demonstrate its value to industry.

Case histories are provided for the TMIC systems for both new construction and maintenance projects.

Keywords: Corrosion Under Insulation, Titanium Modified Inorganic Copolymer

THE TRAUMA OF CORROSION UNDER INSULATION

Corrosion under insulation (CUI) is a unique and challenging problem as evidenced by significant corrosion on pipes and vessels at many industrial plants worldwide. The CUI process is by and large well understood and in essence occurs when water and oxygen penetrate insulation that enshrouds hot steel surfaces where the steel temperature range is ca -5°C to +120°C (1,2). Given that the corrosion rate roughly doubles for every 15 -20°C rise in temperature (up to the boiling point of water) the most aggressive CUI takes place when say pipe spools or vessels operate between 60°C and 120°C.

It is interesting to note that the barrier properties of thermal insulation can cause a slight pressurization of entrained gases such that the boiling temperature of water is elevated above its normal value. Moreover, although it is appreciated that thermal insulation provides an essential function to chemical, petrochemical and refinery processes, unfortunately the insulation materials themselves are invariably porous, prone to mechanical damage, and collude against piping and vessels by potentially harbouring moisture (thus hiding unwanted chemical activities, so-to-speak) (3).

Where the opportunity for moisture ingress exists, insulation materials typically absorb and hold water where it is least wanted, ie against the steel substrate. The source of the moisture varies, say from condensation occurring due to a rapid cooling stage in the process cycle - or merely a maintenance outage - to rain entering through a leak in the insulation cladding itself. While technologies have significantly improved to exclude water from various types of insulation, in the final analysis the barriers that surround insulation can never be guaranteed impenetrable.

To make matters worse, when moisture passes through insulation and coincides with repetitive thermal cycles, the concentration of corrosive contaminants readily occurs. Contaminants, whether present from general atmospheric pollution or from local concentrated sources in the surrounding plant, can be carried in with the moisture. As a result, the next high temperature cycle evaporates the water to leave the contaminants behind. Over time as each cycle is repeated, the concentration of contaminants is raised thereby increasing the aggressiveness of the microenvironment at the insulation – substrate interface. Despite most incidences of CUI being active for relatively brief periods, the combination of temperature and a natural concentration build-up of corrosive contaminants ensures that CUI is a formidable foe in the war on corrosion. In fact, corrosion rates in the range of 1.5-3.0 mm per year have been reported (4). This reflects a corrosion rate that is more than 20 times greater than that due to atmospheric corrosion alone.

Adding insult to injury, the presence of the insulation itself reduces, if not prevents, visible signs of CUI from being detected and monitored. Since CUI can stealthily continue unabated, it is often undetected until perforation of a pipe or vessel wall occurs and the plant operation brought to a grinding halt. Importantly, therefore, the cost hazard of CUI lies not in the realm of planned remediation or replacement, but in the much greater realm of emergency repairs, lost production, potential environmental costs from leaks or spills, and deleterious health and safety impacts for the facilities' occupants.

Don Harrop, President of the European Federation of Corrosion summarized the situation neatly with a "... CUI is a latent problem that will always present a risk wherever there is a need to thermally insulate plant and equipment. However, the degree to which it is prevalent lies to a great extent in how much respect it is afforded during design and throughout operational life – it is a problem that is not in a hurry to show itself, but late notice of its arrival is inevitably costly to correct..." (5).

IMPERFECT TREATMENT OPTIONS

The hazards of CUI and its severe cost ramifications have been widely recognized by industry and during the past three decades effective solutions to prevent CUI have been diligently sought. NACE International authored RP0198 "The Control of Corrosion Under Thermal Insulation and Fireproofing Materials – A Systems Approach." Notably in RP0198 is the statement: "The best solution to preventing Corrosion Under Insulation (CUI) is to use a high performance coating system ..." (6).

While on the one hand CUI is problematic to industrial plants, on the other hand it presents difficulties for coating formulators in the protective coatings theatre of operation. Coatings to combat CUI must have several characteristics that work effectively in combination with one another. They must not degrade at the high operating temperatures of process equipment, they must resist the induced stresses from thermal expansion and contraction of steel, provide an adequate barrier to the corrosive contaminants present, and resist exposure to hot water and water vapour. In addition, the practical aspects of surface preparation for, and application of, the coatings plays a pivotal role. And while several early types of protective coatings are somewhat effective against CUI, each has limitations that preclude their use as an overall solution to CUI.

Epoxy-phenolic coatings are often a common choice to mitigate CUI. They can be applied at film thicknesses that, in combination with their highly cross-linked polymer structure, provide excellent barrier properties to prevent corrosion. However, the organic chemistry of epoxy-phenolic coatings limits their in-service temperatures to a maximum of 230°C (450°F). Temperatures above this can cause carbon to carbon bond scission in such coatings, and thus the polymer begins to carbonize and become ineffective.

Switching to inorganic coating chemistries of certain early silicone-based coatings, or alkyl zinc silicates, by-passes the temperature limitation imposed by carbonation and such coatings could withstand steel temperatures beneath thermal insulation of up to 540°C (1000°F). However, this approach also imposes other limitations. Many silicone based coatings have a maximum dry film thickness (DFT) of 3 mils (75 microns) which meant that they could only provide limited barrier protection. Further, these silicone coatings exhibit both poor resistance to thermal cycling and, more importantly, thermal shock.

At first sight the zinc silicate coatings showed promise and answered the film thickness limitation of the silicone coatings by virtue of their ability for sacrificial galvanic protection. Also known as inorganic zinc (IOZ) coatings, they were recognized to provide excellent atmospheric

corrosion resistance and were widely used in early years to guard against the potential ravages of CUI. Alas, however, the aggressiveness of CUI conditions soon revealed that the sacrificial nature of zinc was also rapidly accelerated, to the extent that their excellent protection was only provided for a duration of a few years. With reference again to NACE RP0198 the document specifically addressed this limitation, stating: "Inorganic Zinc Coatings or Galvanizing shall not be used under thermal insulation in the 50-150 °C (120-300 °F) service temperature range for long term or cyclic service. Zinc provides inadequate resistance in closed, sometimes wet environments." (6).

Against this backdrop of liquid coatings, one tried and true solution to the issue of CUI was to go beyond polymeric coatings to a purely metallic coating: thermal metal spray, as exemplified by Thermal Spray Aluminum (TSA). From the performance perspective, TSA has proven itself by demonstrating a zero maintenance service life of 20 years or more of protection against aggressive CUI. Furthermore, TSA has another benefit by being resistant to mechanical damage.

Notwithstanding, the impressive performance of TSA is only achieved with its proper application to properly prepared substrates. In actuality, TSA requires a minimum NACE No.1 / SSPC-SP5 white metal abrasive blast with a profile of 3.5 – 5.5 mils (85-135 microns). TSA also requires specialized application equipment and training to apply it correctly. Without tight application control, TSA can experience loss of adhesion, blistering and premature failure. So these factors make TSA far more suitable for application in controlled shop conditions for new construction projects. An important consideration is that plasma or electric-arc spray application methods needed to successfully apply TSA can also result in a porous coating structure that is likely the limiting factor on an anticipated 20 year plus service life. Certainly, without the coating porosity, even longer coating service life could be expected from TSA.

A NEW JOURNEY TOWARDS HEALTH

Due to the limitations of current approaches, new attempts have been made to develop novel and highly effective polymeric coating technologies that address the gamut of challenges presented by CUI. The results of these efforts have recently come to fruition in the development of a new class of high performance coatings based upon what is described as Titanium Modified Inorganic Copolymer (TMIC) technology.

When formulated with metallic aluminum flake pigmentation, TMIC technology provides a high temperature resistant, thick film barrier coating with sufficient flexibility to withstand the rigours of thermal cycling.

In addition to the in-service performance, coatings based on TMIC technology can also be applied by conventional spray, airless spray, and brush and roller techniques to SSPC-SP6 commercial blasted surfaces. This ensures that coatings derived from TMIC technology are suitable for both new construction and field applications.

Test Method – Coatings Testing for CUI

In the development of the TMIC technology the realization dawned that there were no recognized standard test protocols suitable to evaluate coatings against the unique challenges of CUI. Therefore, considerable work was undertaken to develop a new test method to characterize the performance of candidate coatings under CUI conditions.

A new test method was developed, the Cyclic Pipe Test, where sections of steel pipe are abrasive blast cleaned to an SSPC-SP10 near white metal standard and then coated with the candidate coating by spray application (7). After curing for 7 days at 25°C (77°F) the coated pipe is then insulated with a 2-inch thick wrap of calcium silicate insulation and the exterior of the assembly sealed with aluminum foil. This construction simulates the worst case scenario for cladding and insulation used in industrial applications, as calcium silicate readily wicks moisture and can hold 20-40 times its weight in water. An end view of a cyclic pipe test assembly showing the cross-section structure is shown in Figure 1.

The accelerated exposure component of the test method consists of saturating the insulation with a solution of 1% sodium chloride. Once the insulation is thoroughly wetted, one end of the pipe assembly is heated on a hot plate to 450°C (852°F) for 8 hours, creating a temperature gradient along the length of the pipe down to 60°C at the opposite end of the pipe. (Figure 2). After the 8 hours is complete, the insulation is re-saturated with the salt solution, removed from the hot plate and allowed to cool under ambient conditions for 16 hours. This regime of exposure represents 1 cycle, which is graphically represented in Figure 3. In this study the coated and insulated pipe sections were exposed to 30 cycles before being evaluated for corrosion resistance.

Coatings Under Test

In this study, the performance of a coating based on TIMC technology was compared against two competing state-of-the-art inorganic polymeric coatings. The customized and new Cyclic Pipe Test method was adopted. The coatings, and their claimed performance attributes are described as follows, and summarized in Table 1:

Technology A

Technology A consists of a two-component coating derived from TMIC technology. It was claimed to provide temperature and corrosion resistance in both insulated and uninsulated service in operating temperatures up to 565°C (1050°F). Hereafter designated simply as TMIC, this coating is also stated to be suitable for use over a range of thermal cyclic situations for equipment operating up to 400°C, including re-heat cycles, cool down and steam-out conditions. TMIC is reported to possess excellent resistance to "thermal shock" experienced during rapid and frequent temperature cycling. In addition, TMIC is recommended for application over hot substrates up to 120°C (248°F).

The TMIC coating was evaluated as a single applied coat at 7 mils (175 microns) dry film thickness (DFT).

Technology B

Technology B is an inorganic polymer containing micaceous iron oxide (MIO) barrier pigmentation and is available in a single-pack formulation. With a claimed temperature resistance up to 650°C (1200°F) in continuous service it is also said to be able to withstand intermittent exposures up to 720°C (1328°F). Technology B may be applied to hot substrates up to 260°C (500°F).

Technology B was evaluated as a two coat system with a total system DFT of 10 -12 mils (250-300 microns).

Technology C

Technology C is a modified silicone copolymer provided in a two-pack formulation. It is said to be temperature resistant up to 538°C (1000°F).

Technology C was evaluated as a two coat system with a total system DFT of 8 -10 mils (200-250 microns).

PERFORMANCE RESULTS

After each coating was subjected to 30 cycles of the Cyclic Pipe Test, the pipe assemblies were dismantled and the condition of the coating evaluated. Figure 4 shows a comparison of the condition of the three coatings after 30 cycles were completed. In the photo the maximum temperature exposure is at the left side (450°C), with the lowest temperature exposure (60°C) at the right side. For reference, the critical CUI temperature range is also indicated. Please note the corrosion on the left-hand end of the pipe was due to the pipe-end remaining uncoated during the test to provide thermal coupling between the hot plate and pipe sample. Therefore, the corrosion at the immediate pipe end is not considered within the evaluation. At first glance the performance of the Technology A (TMIC) does not appear to be much different in comparison to that of Technologies B and C. However, upon closer inspection significant performance was observed as outlined below.

Closer views of the coatings after test exposure are presented in Figures 5 through 10. It is noteworthy as evidenced by Figures 5 and 6 that Technology A (TMIC), did not exhibit breakdown within the CUI range. In addition, Technology A performed very well at the higher temperatures of 235 and 300°C.

Figures 7 and 8 show the test results of Technology B (inorganic polymer with MIO). Technology B exhibited small areas of rust development in the critical CUI temperature range, below 150°C. Further, it showed a marked coating breakdown at 235°C, and almost complete coating deterioration at 300°C. This indicated that increasing temperature exposure put additional stress on the coating.

The thermal stability and corrosion protection afforded by Technology C (modified silicone copolymer) is shown in Figures 9 and 10. It can be seen that Technology C exhibits

several spots of rust development below 150°C, within the critical CUI temperature range. Additionally, it shows pronounced rust breakthrough and staining at 300°C, and severe rust development at 235°C. This indicates that while the coating is temperature resistant, its protective barrier properties are limited under the conditions tried.

RISK MANAGEMENT

In Probabilistic Risk Assessment, risk is loosely defined as follows:

Risk = (Probability of a failure occurring) X (cost consequence incurred by a failure)

First, consider the cost consequence portion of the risk equation. As discussed earlier, CUI is difficult to detect and often not identified prior to the perforation or rupture of an insulated pipe or vessel during normal operations. As such, CUI cannot be effectively dealt with by a strategy of repair or replacement during regularly scheduled maintenance outages, and results in the much higher costs of emergency repair, and even larger costs of lost plant production. As these costs can be orders of magnitude larger than scheduled maintenance costs, the probability of a CUI failure does not need to be particularly large in order for the risk cost to be substantial.

Second, consider the failure probability portion of the risk equation. Since the cost consequence of a CUI failure can be intolerable, there is substantial value in employing methods to reduce the probability of a CUI failure to the minimum achievable by the technology available. The new TMIC technology coating reduces the probability of a CUI failure in two different ways. By providing a superior service life performance in comparison to other traditional high-heat polymer coatings, TMIC more effectively manages CUI, diminishing the probability of a failure to a greater degree.

Less apparent is an additional factor with using traditional coatings that can increase the probability of a CUI failure. As discussed previously, each traditional coating solution for CUI has a different form of drawback in terms of service or performance. Therefore, with traditional coating solutions to CUI, each different set of service conditions will require that a knowledgeable evaluation is made to identify the coating technology best suited to address the particular circumstances. This results in a complex decision matrix for the selection of the CUI coating solution, and raises the potential for the specification of a suboptimal coating solution. Further, industrial processes frequently change over the duration of a plant life, such that a correctly specified CUI coatings solution may move outside of its applicable operating conditions. Lastly, normal plant operations regularly involve process upsets that may not have been accounted for in the selection of the CUI coating. From this viewpoint, specifying TMIC coating technology that can be universally used under all conditions to provide effective mitigation of CUI can greatly reduce the risk of a CUI failure.

In a nutshell, TMIC technology is a powerful tool to substantially reduce the risk that industry endures at the hands of CUI.

TRANSCENDENCE

Given the sizeable cost consequence of a CUI-induced failure, it is not unreasonable to pursue the best possible preventative approach, an approach that eliminates all compromises from the selection process. As was discussed earlier, even with the advancement of TMIC technology, at the present time Thermal Spray Aluminum still provides the longest service life of protective coatings. Yet, with the inherent porosity of TSA (see Figure 11) limiting its maximum service life, and the difficulty of TSA to be effectively used in maintenance or field applications, there is clearly room for further improvement.

Fortunately, the universal applicability of TMIC technology for high heat and under-insulation service, combined with its application tolerance, makes a perfect complementary product strategy for TSA. In new construction, TMIC can be used to effectively seal the porosity in TSA, extending the effective life of the TSA to 25-30 plus years. Where TSA is in service and approaching its end-of life, TMIC can be used in tandem as a maintenance overcoat, again filling the porosity and adding additional barrier protection to extend the life of the TSA. Therefore, by combining TSA and TMIC in a duplex coating system, a transcendent solution is finally realized to deal with CUI. The result is a far cry from the trauma of CUI.

Figure 12 presents a cross-section view of this transcendent solution, namely a TSA coating with the porosity sealed by a topcoat based on TMIC. The TSA coating applied at 6-8 mils (150-200 microns) is first “mist coated” with a thin layer of TMIC, equivalent to 1-2 mils (25-50 microns) DFT. The mist coat penetrates the TSA porosity and consolidates the matrix. Next a full barrier coating of TMIC is applied at 3-4 mils (75-100 microns) DFT to embed and seal the TSA. It should be noted that the application of the “mist” coat is a necessary and critical step. Without the mist coat, some porosity within the TSA would remain open and thus remain as potentially weak points that could suffer premature failure.

Supporting the combined use of TSA and TMIC is a laboratory evaluation for the weld repair of a TSA coated pipe. Two sections of the latter were welded together (Figure 13). The weld joint area was prepared to SSPC-SP11, power tool cleaning to bare metal (Figure 14) and then coated with TMIC (Figure 15). The pipe sample was then subjected to two 8 hour cycles of 400°C and examined (Figure 16). As can be seen, there is no identifiable degradation of the TMIC or TSA.

CASE HISTORIES

Regardless of how well designed a laboratory simulation of a service environment is, it is still an approximation or indicator of performance and does not fully reflect how a product will perform in real life service. The following case histories outline the performance of TMIC in actual service conditions.

(1) Propane Treater Units with Thermal Cycling

Two insulated mild steel propane treater vessels shown in Figure 17, are located at Port Bonython, Australia, and had previously been coated with an inorganic zinc silicate product. The surface area of the vessels totalled approximately 200 m². The vessels operate under a

cycling temperature profile consisting of a rise from 40 °C to 260 °C instantly, remain at 260 °C for 3 hours, slowly decrease over 3 hrs to 80 °C, then rise from 80 °C to 260 °C instantly, remain at 260 °C for 21hrs, and then slowly decrease to 40 °C for 140 hrs. Both vessels experienced widespread failure of the zinc silicate coating and aggressive CUI. This is shown in Figure 18.

In 2005 the vessels were exposed, abrasive blasted to SSPC-SP6 with a profile of 1.5 mils (35microns) and coated with a single coat of TMIC at a DFT of 6-8 mils (150-200 microns) using airless spray equipment (Figure 19). The vessels were re-insulated and put back into operation.

One and two years after application of the TMIC, an area that had previously experienced severe CUI was exposed and the condition evaluated. Figure 20 shows the TMIC intact and exhibiting no signs of deterioration or CUI activity.

(2) Incinerator with Severe CUI Conditions

In 2007, a newly constructed incinerator tower failed after only 7 months in service due to severe CUI. The unscheduled shutdown resulted in a loss of profit of \$100,000 USD per day until the incinerator could be repaired and adequately protected.

The remediation included abrasive blasting the tower to an SSPC-SP5 white metal blast and applying TMIC by brush and roller in 4 coats to a total system DFT of 8 mils. To date the incinerator has operated without any problems, indicating the CUI has been effectively arrested.

The condition of the incinerator before and after the application of TMIC is presented in Figures 21 and 22.

(3) Swedish Gas Refinery with High Heat Service

In 2006, a gas refinery in Sweden specified TMIC for new insulated piping within the plant that would later operate up to 350 °C (660 °F). Figure 23 shows pipe sections after coating and installation.

After one year in service the piping was inspected and the insulation was found to be wet. After 2.5 years in service the piping was re-inspected and no indications of coating deterioration or CUI were found. Figures 24 and 25 show the condition of the piping during the inspection.

(4) Texas Gas Dryer Unit: Oldest TMIC Installation

Gas dryer units in a Texas refinery with a history of rapid deterioration of under insulation coatings were selected for the first industrial field trial of TMIC technology. The dryer units cycle between -12°C (10°F) and 200°C (400°F) over a 4-5day cycle. Previously several different polymeric coating technologies had been used to protect the dryers, and in all cases the coatings had failed within a period of 6-12 months in service. Figure 26 and 27 show the condition of the dryer after the last coating failure. Due to the lack of success with other coatings, and the inability to apply TSA to the on-site structures, the refinery decided to try TMIC in hopes that this would solve the CUI problem.

In 2004 the TMIC coating was applied to the dryers. Due to site safety and operational limitations, abrasive blasting was not possible, so the surface preparation prior to the TMIC coating application consisted of SSPC-SP2 and SP3, hand and power tool cleaning. Figure 28 shows the surface preparation prior to the application of the TMIC. The TMIC was applied in two coats for a total DFT of 8-10 mils (200-250 microns).

One year later, the dryer units were inspected showing no rusting or coating degradation present, as shown in Figure 29. At present, the dryers have operated for 5.5 years without any indications of CUI.

CONCLUSIONS

The results of the Cyclic Pipe Test yielded the following conclusions:

- Technology A (TMIC) is superior to Technology C, which is in turn superior to Technology B for protection against corrosion under insulation.
- Technology A (TMIC) performs up to 450°C without breakdown.
- Technology B fails by blistering and rusting at temperatures above 235°C.
- Technology C fails by cracking and rusting at temperatures above 200°C.

The development of TMIC technology coatings presents a unique first in the struggle to manage corrosion under insulation. TMIC coatings provide a stand alone high level of protection against CUI while avoiding the drawbacks and limitations inherent within earlier high-heat polymer coatings. TMIC coatings are also the ideal complement to thermal spray aluminum to achieve the transcendent coating system that affords maximum protection and service life for under-insulation service.

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TABLE 1:
Candidate Coating Technologies for CUI testing

Coating	Technology Description	No. of Coats & Dry Film Thickness	Claimed Performance
A	Titanium Modified Inorganic Copolymer	1 coat 7 mils Total	Max. Continuous T: 565 °C Max Cyclic T: 400 °C Max Substrate T during application: 120 °C Excellent Thermal Shock Resistance.
B	Inorganic Polymer with MIO	2 coats 10-12 mils Total	Max Continuous T: 650 °C Max Intermittent T: 720 °C Max Substrate T during application: 260 °C
C	Modified Silicone Copolymer	2 coats 8-10 mils Total	Max T: 538 °C



FIGURE 1 – End view of a Cyclic Pipe Test assembly showing the cross-sectional structure.



FIGURE 2 – View showing Cyclic Pipe Test Assembly placed on a hot plate for testing.

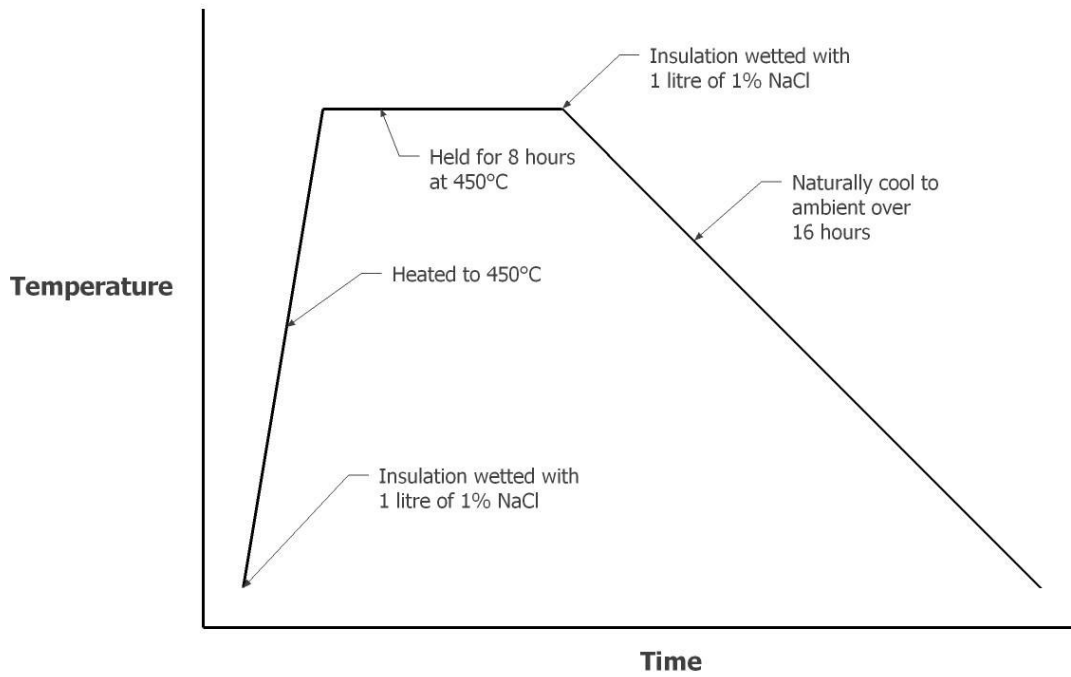


FIGURE 3 – Exposure cycle for Cyclic Pipe Test.

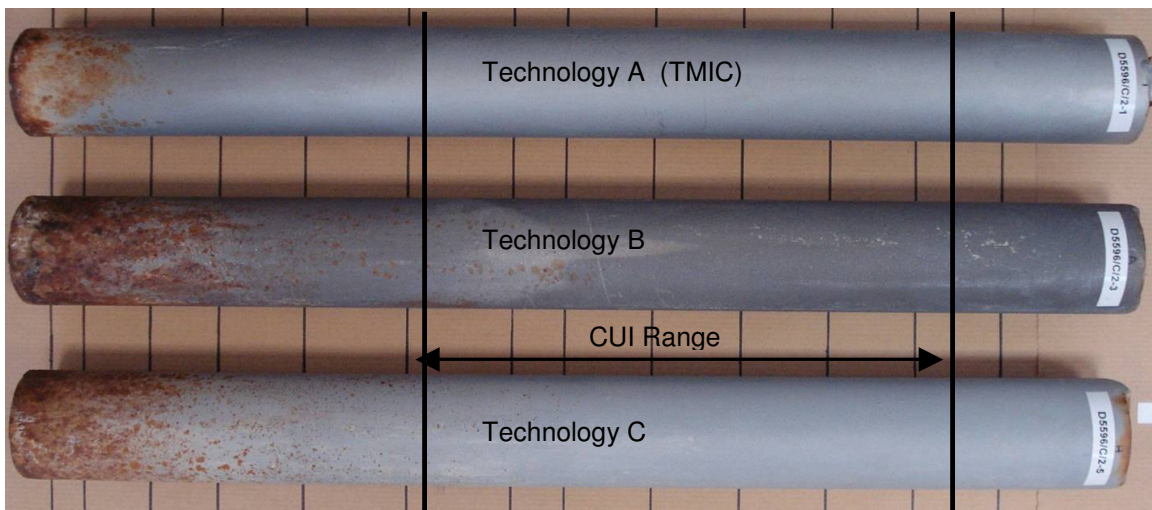


FIGURE 4 – End view of a Cyclic Pipe Test assembly showing the cross-sectional structure.

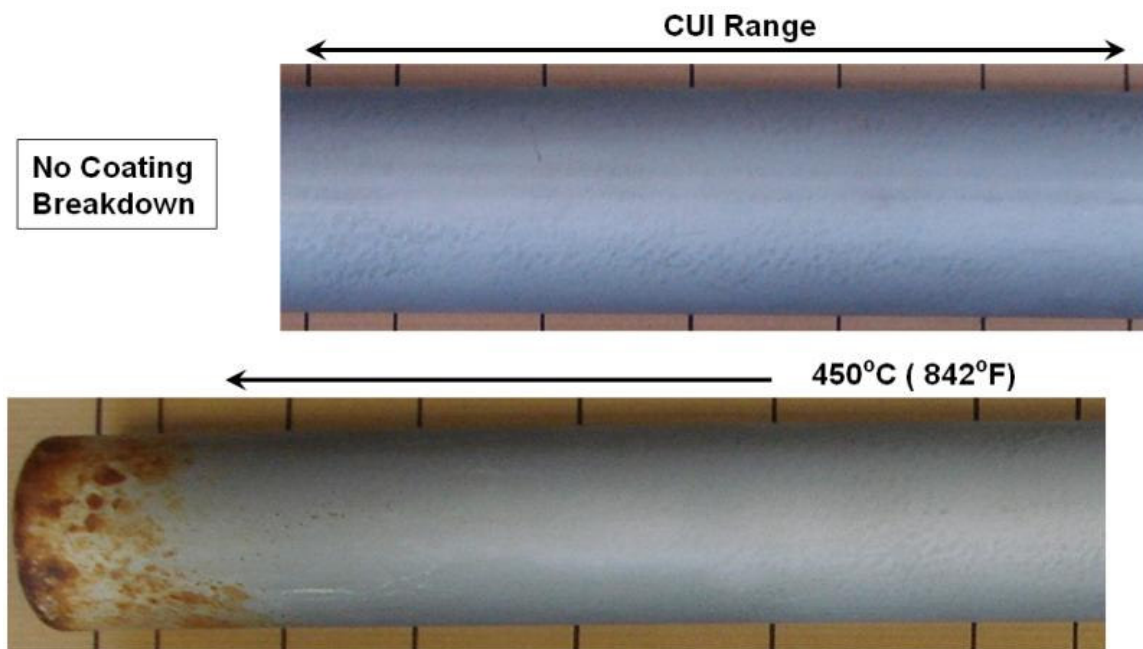


FIGURE 5 – Condition of Technology A after 30 exposure cycles.



Temperature: 235°C (455°F)



**Temperature range: 275 to 300°C
(527 to 572°F)**

FIGURE 6 – Closer view of Figure 5 at specific temperatures.

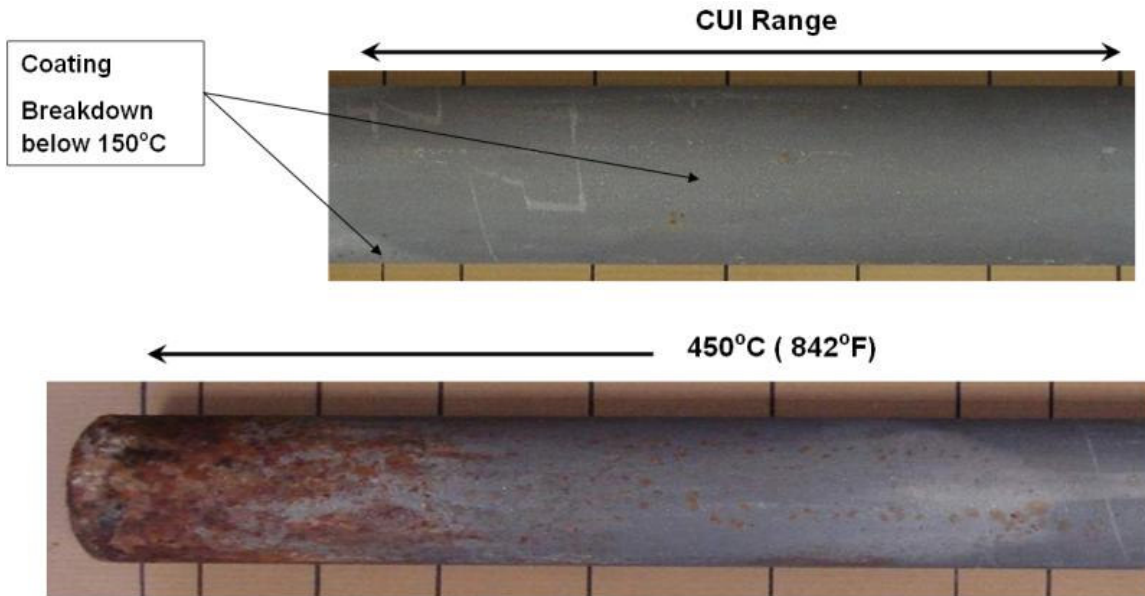
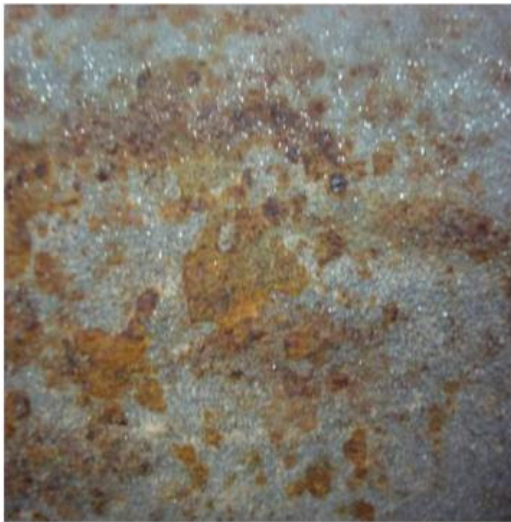


FIGURE 7 – Condition of Technology B after 30 exposure cycles.



Temperature: 235°C (455°F)



**Temperature range: 275 to 300°C
(527 to 572°F)**

FIGURE 8 – Closer view of Figure 7 at specific temperatures.

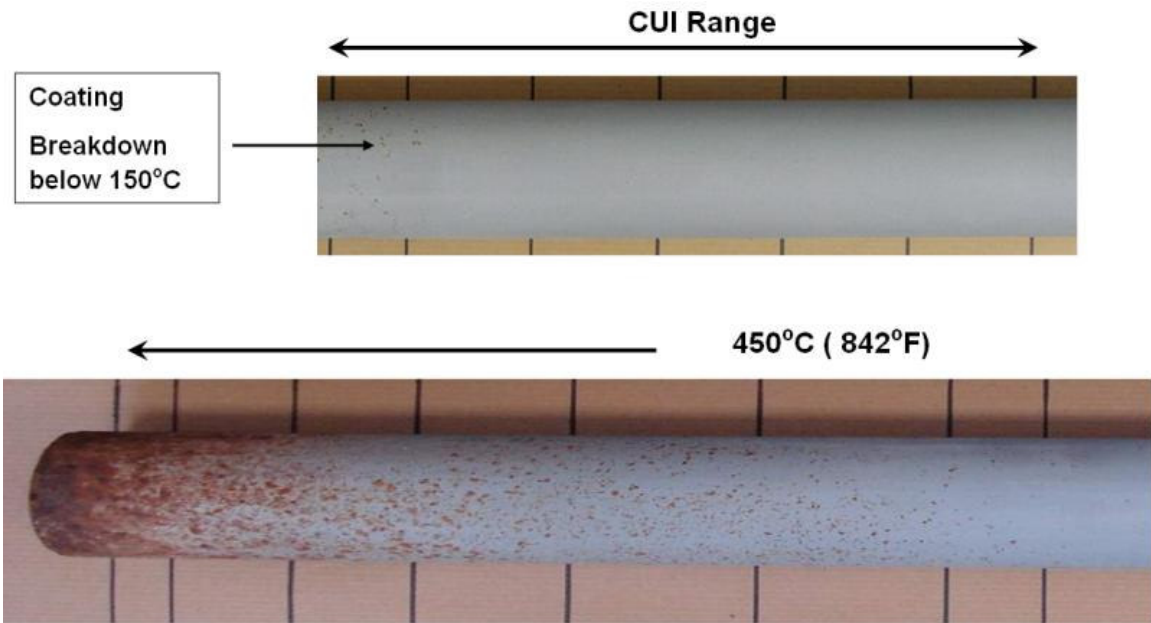
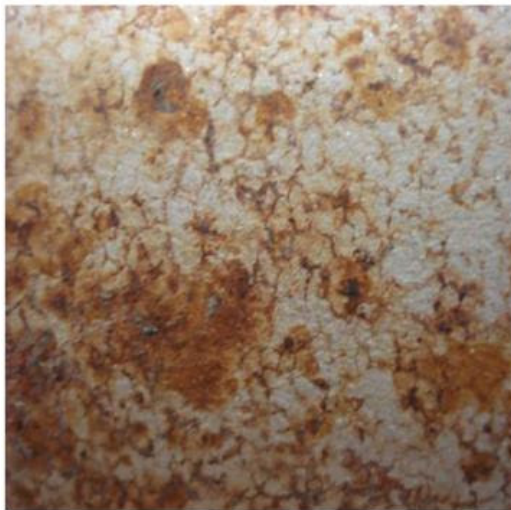


FIGURE 9 – Condition of Technology C after 30 exposure cycles.



Temperature: 235°C (455°F)



Temperature range: 275 to 300°C (527 to 572°F)

FIGURE 10 – Closer view of Figure 9 at specific temperatures.

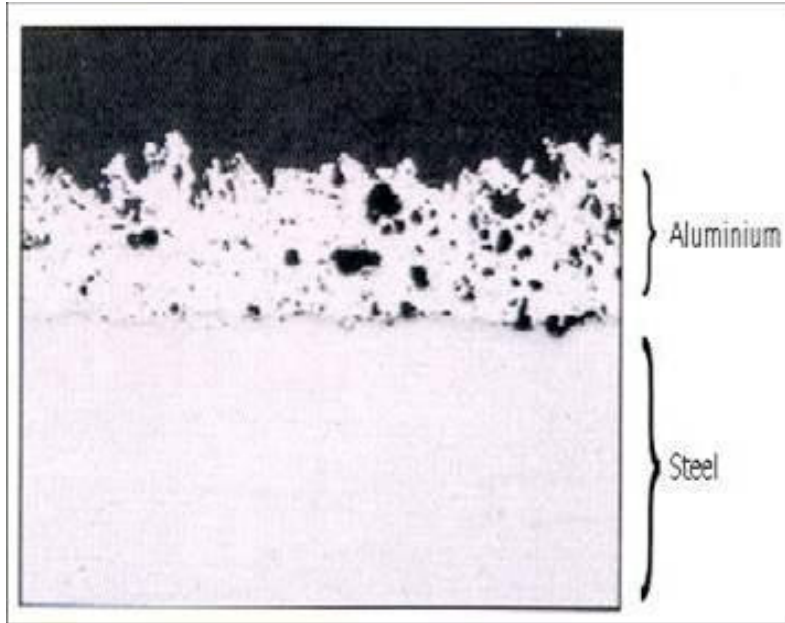


FIGURE 11 – Cross-section view of TSA showing porosity in the coating.

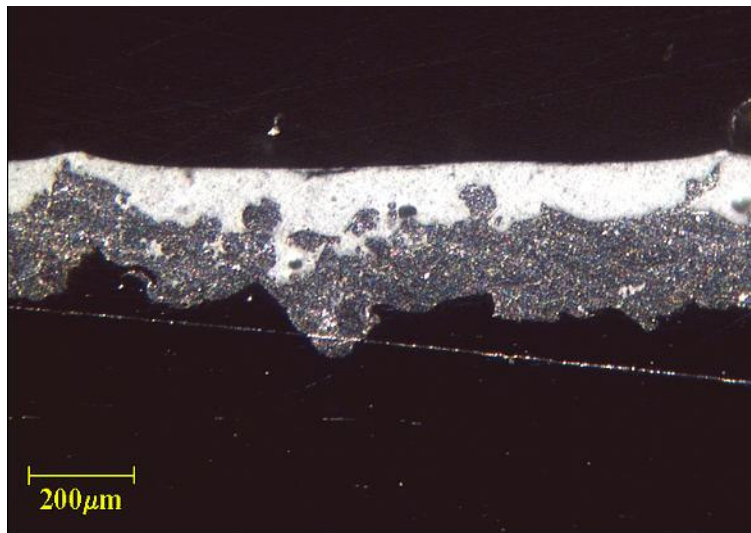


FIGURE 12 – Cross-section view of TSA sealed with a topcoat of TMIC.



FIGURE 13 – TSA coated pipe with welded joint.



FIGURE 14 – Welded pipe joint after surface preparation to SSPC-SP11.



FIGURE 15 – Welded pipe joint after application of TMIC over bare steel and TSA.



FIGURE 16 – Evaluation of TMIC and TSA after thermal cycle exposure.



FIGURE 17 – Propane Treater Vessel.



FIGURE 18 – Propane Treater Vessel – Failure of IOZ and subsequent CUI.



FIGURE 19 – Propane Treater Vessel – TMIC being applied.



FIGURE 20 – Propane Treater Vessel –inspection of TMIC condition after 1 year service.



FIGURE 21 – Incinerator after CUI failure



FIGURE 22 – Incinerator after remediation and TMIC application.



FIGURE 23 – Sweden refinery piping coated with TMIC.



FIGURE 24 – Sweden Refinery Piping – condition of TMIC after 2.5 years service.



FIGURE 25 – Sweden Refinery Piping – condition of TMIC after 2.5 years service.



FIGURE 26 – Texas refinery gas dryer unit showing breakdown of traditional high heat coating after 12 months in service.



FIGURE 27 – Close view of Figure 26 showing severe coating degradation.



FIGURE 28 – Surface preparation of gas dryer unit prior to application of TMIC.



FIGURE 29 – Inspection of TMIC after 1 year in service showing no coating breakdown or rusting.