

A Hot-Spread Epoxy Phenolic Coating for CUI Mitigation

From Confusion to Fusion for Facility Owners

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It is fair to say that maintenance in the worldwide oil and gas industry has changed dramatically over the past 10 years. Facility owners are more than ever looking to reduce shutdown times, to improve plant efficiency and to extend plant lifetimes. With this comes the increased industry understanding about corrosion under insulation, with its deleterious impact and the ongoing desire for pragmatic high-performance and cost-effective coating solutions.

It is well known that CUI often goes unabated and undetected on carbon steel pipes, valves and vessels. When an asset eventually perforates and fails, massive costs can be incurred for the facility owner—either from lost production, chemical spills, environmental clean-up, health and safety consequences or inordinately expensive repairs. CUI maintenance work can take up to 50% or more of a typical oil and gas facility's maintenance budget. With such a heavy impact on resources when CUI maintenance needs to be carried out, it is imperative the rehabilitation must be done right, the first time.

Factoring in operational losses, the cost to shutdown equipment can be up to \$100,000 per hour, so the ability to carry out planned or even emergency maintenance while the facility is operating can be very attractive. However, coating piping and equipment that is still in operation causes logistical, technical and practical challenges for traditional coating technologies. Although most traditional coating solutions are capable of application at elevated temperatures, few have been deliberately formulated to be applied in this way.

This article will review the current protective coating technologies on the market that are applied directly to hot process piping for CUI protection applications. Exemplified by a novel hot-spread epoxy phenolic coating that represents a fusion in molecular engineering, and fusion to the applied substrate, it will be shown how properly formulated protective coatings for hot-steel application on low-grade surface pre-treatments:

- Are derived from an understanding of iron (oxyhydr)oxide types;
- Assure facility owners cost reductions in CUI mitigation;
- Help eliminate confusion for owners, engineers and specification authorities with coating selection; and
- Provide valuable coating additions for the maintenance contractor's armory.

Applications of the hot-spread epoxy phenolic technology to hot, rusted steel pipes and vessels in the oil and gas industry will be highlighted.

BACKGROUND

The most CUI-prone environment for carbon steel pipes and vessels arguably occurs when water is continually replenishing oxygen at a steel-insulation interface where the steel temperature ranges between 25 F (-4 C) to 350 F (175 C). Factors such as dissolved oxygen, corrosive salts from the water or insulation, hydrophobicity or hydrophilicity of the insulation, isothermal or cyclic conditions, whether rain leaks through damaged cladding and porous insulation, and difficulties associated with detection of CUI, all come into play to make this type of corrosion an insidious problem to contend with.

A robust CUI deterrence strategy is available from coating systems including liquid-applied epoxy phenolic, and inert multi-polymeric matrix (IMM) coatings. Both of these coating types are suitable for insulated and non-insulated carbon steel and stainless-steel pipes and vessels, as evidenced in the SP0198 standard.¹

Despite the efficacy of these coatings, there is considerable room for further formulation and performance improvements. This is highlighted with today's increasing maintenance needs for superior coating performance for field application on hot, and corroded, steel pipes and vessels. A goal of facility owners in this case is to safely refurbish assets that remain operational with minimal surface preparation, easy coating application and re-insulation within minutes of the coating being applied.

Before discussing these coating systems further, it would be instructive at this point to give a brief overview of the liquid coating types and binder chemistries that have become a prominent strategy to deal with the demanding services of CUI, starting with a consideration of the inappropriate use of inorganic zinc silicates. Subsequently, the criteria that underpins what is necessary for the design of a new hot-spread epoxy phenolic coating will be examined. Thereafter, the performance attributes of this coating technology will be evaluated.

COATINGS TO ADDRESS CUI

Inorganic Zinc Silicates

It is common in the petrochemical and refining industries to use inorganic zinc silicate primers for corrosion protection on carbon steel piping. This is especially true in fabrication shops where the quick-drying features of inorganic zincs significantly enhance productivity.

Inorganic zincs protect steel by an initial galvanic action where the zinc in a porous film has a high surface area and is the anode in a corrosion cell. On continued exposure to the elements, the porosity of the zinc coating diminishes and the zinc anode is denuded as the zinc reacts with oxygen, moisture and carbon dioxide, respectively forming tightly adherent zinc oxide, zinc hydroxide and zinc carbonate (and other zinc salts) that fill the film porosity.

Inorganic zinc coatings have proven capable of withstanding temperatures up to 750 F (400 C) in non-immersion service without any loss in performance. Based on actual field experience, the use of an inorganic zinc as a stand-alone coating under insulation during hot and wet conditions has proven to be detrimental in protecting carbon steel. NACE SP0198 discourages the use of inorganic zinc under insulation.

Several theories have been proposed to explain the failure mechanism of inorganic zincs in CUI mitigation service. One popular theory suggests a polarity or corrosion potential reversal, or inversion, at 140 F (60 C) where the zinc coating becomes cathodic to steel, which leads to an acceleration in carbon steel corrosion. Other theories, however, discount the possibility of a polarity reversal of zinc and iron. Instead, the reactivity of zinc in a given service environment to form zinc compounds is considered to be the reason that zinc is consumed at elevated temperatures in CUI service. Zinc is an amphoteric metal that exhibits a parabolic corrosion curve, which shows that even at room temperature zinc will be consumed outside a range of pH 5.5 to 10.5 (a range that will narrow as the temperature is increased).

IMM Technology

Due to the higher bond strength and resistance to cleavage of the Si-O bond (452 kJ/mol) in polysiloxane coatings compared to the C-O (358 kJ/mol) bond in organic epoxy coatings, both the single-component (1K) and two-component (2K) IMM polysiloxane coatings have much higher thermal stability and resistance to degradation than more vulnerable epoxy phenolic organic coatings.

From an asset integrity perspective, IMM coatings generally provide threefold resistance to thermal aging, thermal shock and thermal cycling, as well as cost reduction with low life-cycle costs, good performance and overall risk reduction for an owner.

Although well-formulated IMM coatings afford broad anticorrosion performance from cryogenic temperatures of -321 F (-196 C) up to 1,202 F (650 C), when used solely between ambient and 302 F (150 C) most of them require post-curing to provide anticorrosion protection. For corrosion protection for steel at ambient conditions, especially for steel pipes, valves or vessels stored in lay down yards awaiting erection and insulation, IMM coatings will normally require zinc rich primers for ISO 12944:2018 C5 high durability (with few notable exceptions).²

In the case of IMM coating applications to hot surfaces, a particular challenge is to avoid pinholes in the film, which can result in corrosion taking place. The short recoat windows of some of the IMM coatings can make repairs difficult and costly. IMM coatings can have poor brush application characteristics resulting in large dry-film thickness variations and a non-smooth surface. Despite being touted to the contrary, several IMM coatings have poor tolerance to hand-tool-prepared (SSPC-SP 2, St 2) surfaces.

Previous research work by the authors has shown that several 1K coatings and some 2K IMM coatings that were applied to steel at ambient temperatures, exhibited foreshortened anticorrosive performance under insulation when isothermal or cyclic service temperatures were less than 392 F (200 C).³ The surprising thermal and thermo-oxidative degradation observed underscores the benefit of getting an initial heat-cure for certain IMM coatings at 392–482 F (200–250 C).

On the one hand, with more extreme services of coating applications to hot steel—some applied up to 600 F (316 C)—the curing characteristics of IMM coatings will theoretically be enhanced by the heat if the coatings are applied in-situ. On the other hand, lesser prepared rusty steel surfaces are not as conducive to long-term IMM coating performance.

Traditional Epoxy Phenolic Coating Technology

For decades, the workhorse coating system for most CUI programs has consisted of two coats of an immersion-grade, high-temperature-resistant epoxy phenolic coating. Prior to the advent of IMM coatings, the greater thermolytic and hydrolytic resistance of these coatings, compared to most Bis-A epoxies, has meant they were essentially the de facto coatings of choice for CUI mitigation.

The recommended film thickness for each coat is typically 4–5 mils (100–125 µm) and, if applied properly, these coatings can sustain continuous elevated temperatures of 392 F (200 C) and intermittent temperatures up to 446 F (230 C). Care must be taken with relatively low-volume solids traditional epoxy phenolic coatings because they are sensitive to over-application. The result is a tendency for the cured

film to crack when overbuilt. Furthermore, epoxy phenolic coatings possess inadequate cure below 50 F (10 C), suffer the potential for extensive erosion and reduction in film thickness when used uninsulated in hot and humid conditions, and are costly to repair when damaged.

While these coatings may be conducive to application to hot surfaces on assets operating up to 248 F (120 C), they were not specifically designed for application to hot and rusted-steel pipes, valves and vessels.

Epoxy Phenolic Alkylated Amine Coating Technology

Recently, a novel epoxy phenolic alkylated amine coating has been shown to represent a step-change versus traditional epoxy phenolic coating technology for CUI mitigation.⁴

Specifically formulated for process pipes and vessels, the maximum temperature resistance of this immersion-grade coating is 401 F (205 C), with resistance to spikes up to 446 F (230 C). The epoxy phenolic alkylated amine coating can be used for both insulated and uninsulated carbon and stainless-steel operating between -321 F and 401 F (-196 C and 205 C).

A suite of accelerated coating tests, including in accordance with ISO 20340/ISO 12944:2018, showed that the epoxy phenolic alkylated amine coating exhibits superior corrosion protection, and internal stress dissipation, compared to traditional epoxy phenolic coatings. From a practical vantage point where “money and molecules” are front and center, utilizing this coating technology can increase shop and field productivity, reduce project costs and future maintenance costs, and remove many application headaches for contractors—all the while eliminating drawbacks associated with traditional epoxy phenolic coatings.

The epoxy phenolic alkylated amine coating applies and cures down to 23 F (-5 C) and has resistance to cracking when overbuilt at double to triple the required DFTs of properly applied traditional epoxy phenolic coatings, in comparison. Moreover, in-field applications where hot steel assets are non-insulated and exposed to tropical or temperate climates with high humidity, rain and intense UV, the epoxy phenolic alkylated amine has far greater erosion resistance than traditional epoxy phenolic coatings.⁵ The chemistry and polymer networks of an IMM coating, and a more rigid epoxy phenolic coating versus the somewhat similar but flexible network of the epoxy phenolic alkylated amine epoxy, have been shown schematically elsewhere.⁴

As with IMM coatings, traditional epoxy phenolic coatings, and epoxy phenolic alkylated amine coatings (see the overview of their key properties in Table 1), while they are all used on hot or rusted bare steel surfaces, none of them were specifically formulated to do so as their primary modus operandi.

Table 1: Properties of Coatings for CUI

Property	IMM	Traditional Epoxy Phenolic	Epoxy Phenolic Alkylated Amine
Temperature Resistance	-321 F (-196 C) to 1202 F (650 C)	-321 F (-196 C) to 446 F (230 C)	-321 F (-196 C) to 446 F (230 C)
Direct to Hot Steel Temperature Tolerance Claims	Up to 600 F (316 C)	Up to 302 F (150 C)	Up to 248 F (120 C)
Ambient Corrosion Resistance	Generally, needs an inorganic zinc primer for use at ambient temperatures	Good corrosion resistance at ambient temperatures	Excellent corrosion resistance at ambient temperatures
Drying Time at Sub-Zero Temperature	Not possible	Not possible	10 hours at 23 F (-5 C)
DFT Tolerance	Typically, 2 x scheme DFT	Typically, less than 2 x scheme DFT	At least 3 x scheme DFT
Erosion Resistance (Accelerated Erosion Test Method EN 927-6)	Less than 5% DFT loss after 1 year	More than 50% DFT loss after 1 year	Less than 20% DFT loss after 1 year

In order to engineer a coating for maintenance of steelwork damaged by CUI mitigation with the single purpose of application to hot and rusted bare steel, a lengthy research and development project began several years ago, culminating in the recent genesis of a hot-spread epoxy phenolic coating.

HOT-SPREAD EPOXY PHENOLIC COATING FOR CUI MITIGATION

For most industrial and marine coating projects, the preferred surface preparation for carbon- and stainless-steel pipes, valves and vessels prior to coating application is abrasive blast-cleaning carried out to a pre-determined SSPC/NACE/ISO standard on a clean, contaminant-free surface.

Despite this, with maintenance and repair projects subject to significant economic or environmental constraints, abrasive blasting may not be a viable option. Hence, lower standards of surface preparation have become increasingly more attractive for maintenance and repair work. For instance, hand-tool cleaning, power-tool cleaning, pressure washing (with or without inhibitors or specialty cleaning chemicals) or UHP waterjetting are increasingly employed methods of surface preparation.

(Beyond the scope of the present work, for maintenance and repair there are also different ways to achieve cleanliness of steel using specialty chemical treatments. The plus and minus ramifications of chemical treatments for steel in terms of coating adhesion, and coating performance, is an ongoing area of investigation by the authors.)⁶

Complicating matters, any coating application to hot, rusted pipes and vessels can be problematic for a litany of logistical, safety and practical reasons. Nevertheless, facility owners understandably want to keep costs down and obtain long-term coating life as opposed to having costly Band-Aid coating performance and premature coating failures.

Corrosion: The Nature Of Hot Rusted Steel Surfaces

The development of the hot-spread epoxy phenolic coating resulted from considerations of real-world maintenance surface preparation (such as SP 2/St 2 hand-tool cleaning) and, in particular, the discovery of a pronounced “rusted steel substrate effect.” A thorough understanding of the nature of the substrate surface was paramount. The response of a coating in terms of adhesion, lack of cracking,

fracturing or delamination was found to be a function of the chemical nature of the rust, as well as the chemical and dynamic properties of the coating film.

It is well known that rust is a heterogeneous iron oxide corrosion product consisting of many oxy and hydroxy forms, shown in Table 2.⁷ The iron (oxyhydr)oxide type, and amount formed, will depend upon in-service oxidizing conditions.

Table 2: Iron Oxide Corrosion Compounds Identified on Steel⁷

Oxide Name	Formula	Oxide Name	Formula
Ferrihydrite	$5\text{Fe}_2\text{O}_3 \cdot 9\text{H}_2\text{O}$	Wustite	FeO
Goethite	$\alpha\text{-FeOOH}$	Hematite	$\alpha\text{-Fe}_2\text{O}_3$
Akaganeite	$\beta\text{-FeOOH}$	Maghemite	$\gamma\text{-Fe}_2\text{O}_3$
Lepidocrocite	$\gamma\text{-FeOOH}$	Magnetite	Fe_3O_4
Feroxyhite	$\delta\text{-FeOOH}$		

At room temperature, rust is often a difficult-to-consolidate matrix when coated because it presents an unstable and cohesively weak, loose, flaky and friable substrate as shown in Figure 1. Indeed, coating rusted steel at room temperature requires the judicious use of low-viscosity (less than 25 seconds in a Ford # 4 Cup [ASTM D1200]), non-pigmented, low-contact-angle penetrant sealers, which are beneficial given their penetration into voids in the rust and consolidating the rust matrix prior to the application of a barrier coating.⁸

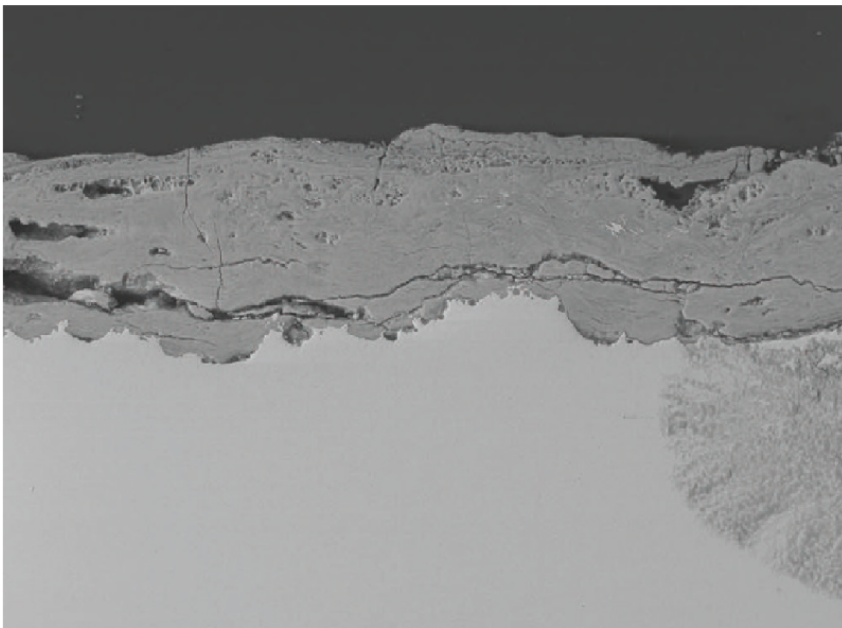


Fig. 1: This SEM photomicrograph of a rust layer shows its friable nature. Photos Courtesy of the Authors Unless Otherwise Noted

Coating rusted steel at elevated temperatures of 140 F (60 C) to 392 F (200 C), however, is an altogether different proposition. In this case, the requirements for success are more onerous, as shown in Table 3.

Table 3: Desirable Properties of a Hot-Spread Epoxy Phenolic Coating

Hot application to live equipment from 140 F (60 C) to 392 F (200 C)
A long wet-edge time to allow easy application by brush and roller
Low continuous dry film thickness (DFT)
Ready to insulate within 15 minutes in CUI maintenance work
Low VOC and minimal HSE risks
Penetration into rust porosity – crevices and voids in the rust – and between adjacent rust particles and layers
Performance based on iron oxide influences – maghemite, goethite and lepidocrocite
Minimal curing stress of the coating in the matrix
Carefully balanced rate of cure of the coating
Optimal stoichiometric ratio of Part A and Part B components
Resistance to hygrothermal stresses: isothermal, cyclic temperatures, micro-immersion service
Excellent corrosion resistance (ISO 12944:2018 Part 9)
Excellent CUI resistance as per the vertical pipe test (ISO 19277)

During maintenance and repair work, it can be difficult to prepare hot steel surfaces to the desired cleanliness, and rust may be present in different amounts prior to the coating application. Against this backdrop, the hot-spread epoxy phenolic was specially designed to go over hot and sub-standard surfaces.

Steel panels were artificially weathered using a proprietary accelerated laboratory method to create a rust layer. Sets of these panels were then heated to 73 F (23 C), 140 F (60 C), 221 F (105 C), and 338 F (170 C). The panels were then wire brushed to the St 2 (ISO 8501) surface cleanliness standard, and x-ray diffraction was subsequently performed on them to quantify the levels of iron (oxyhydr)oxides identified—namely, maghemite, goethite and lepidocrocite (Fig. 2). Maghemite, indicated by the green bar, is the most stable form of rust and the less stable forms of rust—lepidocrocite (red bar) and goethite (orange bar)—can convert into maghemite at high temperature. The degree of conversion is temperature dependent and involves dehydration and oxidation processes taking place.

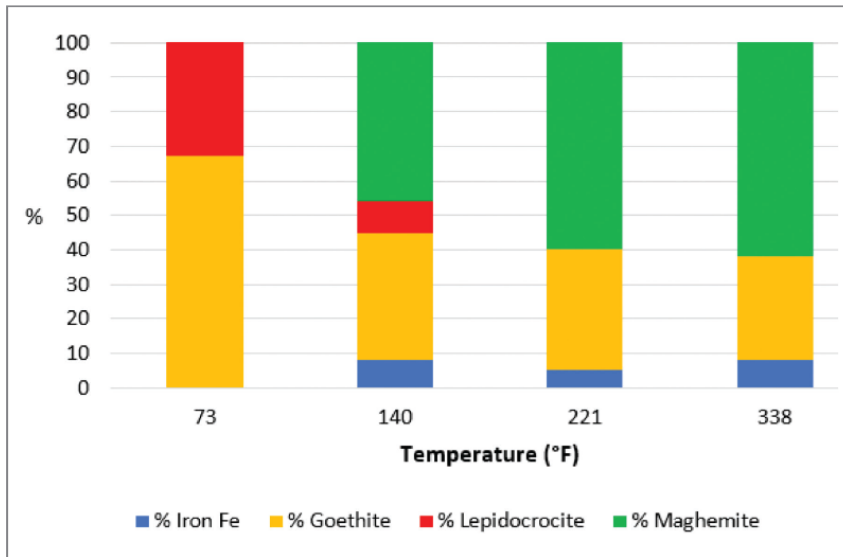


Fig. 2: X-ray diffraction analysis of pre-rusted panels as a function of temperature show the relative percentage composition of iron and rust as maghemite, goethite and lepidocrocite.

SEM analysis of the rust layers after wire brushing to St 2 also showed a significant difference between ambient rusted panels and rusted panels that had been heated to 338 F (170 C), as shown in Figure 3. It was found that after heating the rust layer, a light dust formed that could be easily removed to leave a tightly adherent, maghemite-rich layer—whereas the unheated ambient rust, although adherent, was clearly cohesively weak. For the hot-spread epoxy phenolic, very high values of adhesion (up to 20 MPa) could be achieved.

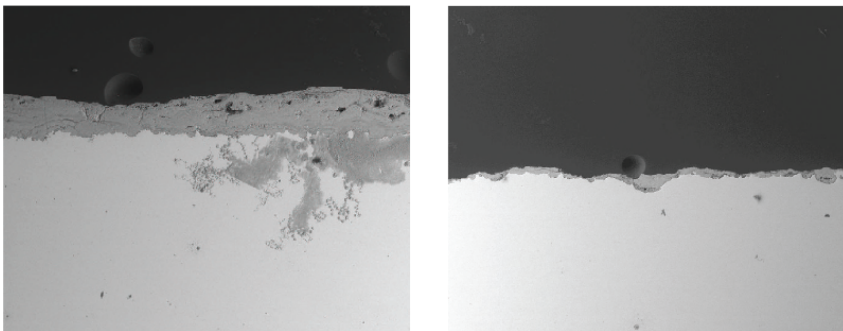


Fig. 3: SEM analysis was performed on rusted panels after wire brushing to St 2. The left panel is after ambient temperature exposure and shows a friable rust layer composed of lepidocrocite and goethite approximately 4 mils (100µm) thick; the right panel is after heating to 338 F (170 C) and here the predominantly maghemite rust layer is tightly adherent and a lot less than 1 mil (25µm) thick.

Panels that had been pre-rusted were prepared to St 2 surface cleanliness and then coated with a commercially available epoxy at 73 F (23 C) and a heat-resistant hot-spread epoxy phenolic coating after the panel had been heated to 221 F (105 C). It was found that the pull-off adhesion rating of the epoxy was less than 2 MPa, but for the hot-spread epoxy phenolic, very high values up to 20 MPa could be achieved (Fig. 4). The failure mode for the commercially available epoxy was a cohesive splitting of the rust layer, whereas for the hot-spread epoxy phenolic, it was a cohesive splitting of the coating itself, highlighting the transition from the unstable lepidocrocite/goethite rust layer to the much more adherent, stable maghemite rust layer.

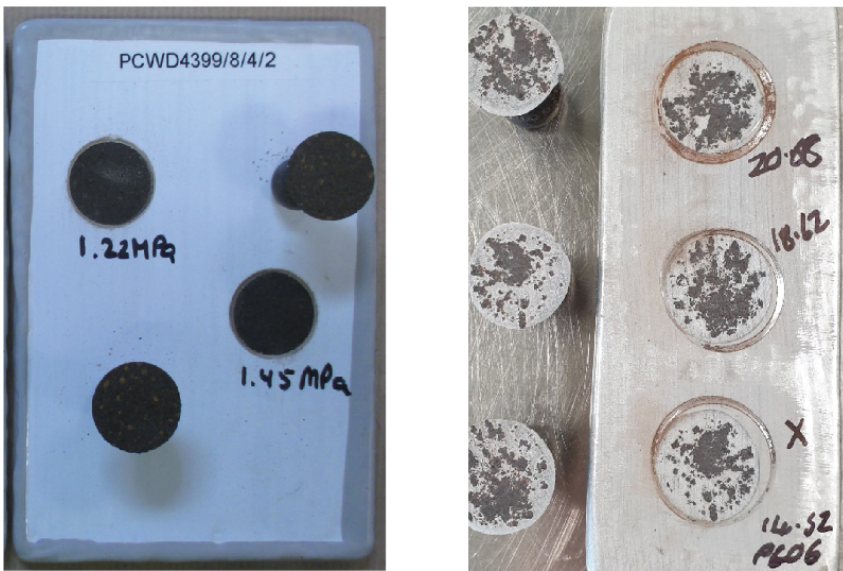


Fig. 4: These are pull-off adhesion results for panels that had been pre-rusted, wire brushed to St 2 and then overcoated. The left panel was coated with a commercially available epoxy at 73 F (23 C), showing less than 2 MPa adhesion due to cohesive splitting of the rust layer; the right panel was coated with a heat-resistant hot-spread epoxy phenolic coating at 221 F (105 C), with adhesion values up to 20 MPa where the failure mode was largely cohesive splitting of the coating itself. All test coatings were applied at the manufacturer's recommended dry-film thickness.

Hot-Spread Epoxy Phenolic Coating Technology

The molecular design of the hot-spread epoxy phenolic coating results from a fusion, or co-reaction, of a carefully selected epoxy phenolic resin cured with a modified phenalkamine curing agent. A "designed fusion," so-to-speak, results from the coating application to the hot rusted steel. The structure of the phenolic resin is shown in Figure 5.

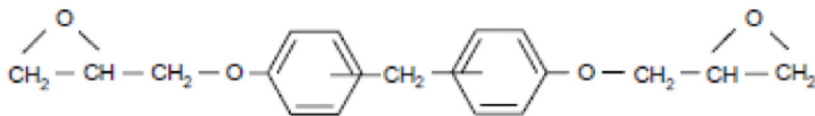


Fig. 5: This shows the chemical structure of an epoxy phenolic resin.

Ideal for combatting corrosion and mitigating the damaging effects of CUI, this molecular approach during formulation yielded a low-viscosity (when applied; viscous before application), immersion-grade, novel hot-spread epoxy phenolic coating. The coating cures rapidly and can be applied in two coats at 3–5 mils (75–125 μm) DFT per coat.

The hot-spread epoxy phenolic coating has a pull-off adhesion rating of over 10 MPa when applied over St 2-prepared carbon steel that was heated to 212 F (100 C), 302 F (150 C) or 401 F (205 C). In all cases, the failure mode was mainly cohesive splitting of the coating highlighting the stability of the steel surface and the consequent excellent adhesion. It also exhibits excellent wettability and sufficient temperature resistance for in-situ applications in the range 140 F (60 C) to 401 F (205 C). Further, the coating cures to a hard film in 15 minutes at 212 F (100 C), allowing the coated surface to be quickly reinsulated in less than half the time it would take with a traditional coating technology (Fig. 6).

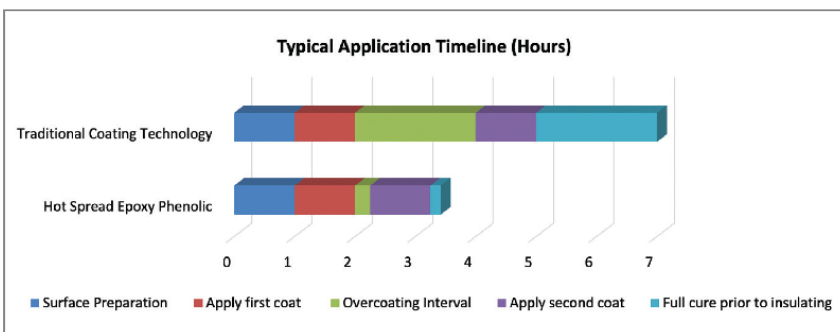


Fig. 6: This compares the typical application time (in hours) for the hot-spread epoxy phenolic versus a traditional coating technology (e.g. epoxy phenolic) based on a steel temperature of 212 F (100 C) and using a combination of brush and roller application methods.

While the rationale to formulate the hot-spread epoxy phenolic coating for hot rusted steel substrates was contingent on the nature of rust itself, it was also contingent on formulation parameters relevant to the permeability and anticorrosive properties of the coating. These attributes are a function of the free volume of the polymer network of the epoxy. Free volume in the polymer network can be envisaged as the unoccupied space, or volume, in the polymer architecture of the coating between spaghetti-like chains of molecules.⁹ Epoxy coatings with large and low free volumes are shown in the schematic diagram in Figure 7.

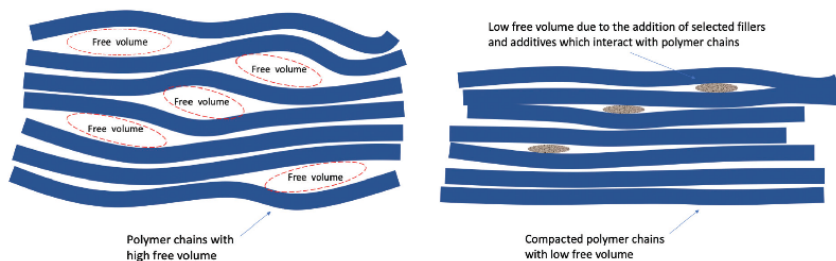


Fig. 7: This schematic shows an example of free volume in epoxy coatings: high free volume (left) and low free volume (right).

To grasp the importance of free volume for the coating with respect to permeability and anticorrosion, consider the coating film to be a glass jar full of marbles. Because of the empty spaces—or free volume—between the marbles, a certain amount of water can be added to the jar. But if the empty spaces between the marbles are filled by the addition of, say, fine sand, then less water can be added.

To enhance the anticorrosive properties of the hot-spread epoxy phenolic coating, its free volume and permeability to oxygen and moisture ingress was formulated to be very low. A reduction in free volume is not physically achieved by filling with sand as in the case of sand in a jar of marbles, but with carefully selected pigments and additives that can interact with polymer chains in the coating.

Another, and more obvious, anticorrosive property requirement in the formulation of a successful hot-spread epoxy phenolic coating was to be able to apply it at elevated temperatures without pinholing. As seen in Figure 8, some IMM coatings can have a tendency to form pinholes after application and curing, and these are defect sites in the coating where corrosion is initiated and propagated. In marked contrast, because of its specific formulation for hot application, the hot-spread epoxy phenolic shows no evidence of pinholes after application and so has excellent corrosion resistance (Table 4).

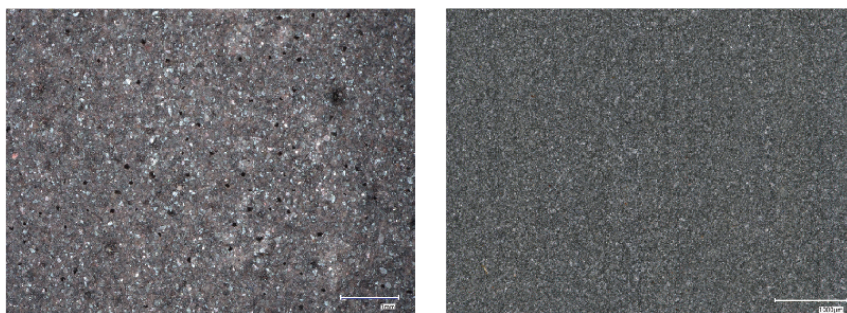


Fig. 8: Some IMM coatings can exhibit pinhole formation and a tendency for corrosion (left), whereas the hot-spread epoxy phenolic technology showed no pinholes and a low tendency for corrosion on hot rusted steel (right). The white bar represents a length of 1 mm.

Table 4: Accelerated Corrosion Resistance Testing (ISO 12944:2018, Part 9) Performance of Hot-Spread Epoxy Phenolic

Surface Preparation	Application Temperature	Corrosion Scribe Creep (mm)
SSPC-SP 10 (Sa 2½)	212 F (100 C)	2
SSPC-SP 3 (St 3)	212 F (100 C)	6
SSPC-SP 10 (Sa 2½)	392 F (200 C)	2
SSPC-SP 3 (St 3)	392 F (200 C)	3

As a corrosion-resistant barrier to protect equipment, the hot-spread epoxy phenolic is ideal beneath thermal insulation on operational assets subject to continuous or intermittent fluctuating wet and dry conditions, and cyclic temperatures up to 401 F (205 C) (with peaks of 446 F [230 C]) and for corrosion protection to steel in operating atmospheric service (Table 4). Once applied, the coating can handle conditions in the critical CUI temperature range recognized by NACE SP0198-2017, namely 25–347 F (–4–175 C) (Table 5).

Table 5: Accelerated CUI Resistance Testing Performance of Hot-Spread Epoxy Phenolic (Vertical Pipe Test, ISO 19277)

Surface preparation	Application Temperature	Duration	Result
St2 (SP2)	212 F (100 C)	30 days	No corrosion or any coating defects evident along the pipe from ambient to 401 F (205 C)

APPLICATION OF THE HOT-SPREAD EPOXY PHENOLIC COATING

For CUI maintenance and repair projects where hot rusted steel assets are in operation at temperatures from 140 F (60 C) to 392 F (200 C), hand- or power-tool cleaning is typically carried out on steel substrates prior to application of the hot-spread epoxy coating.

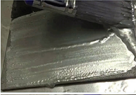



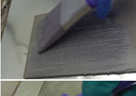
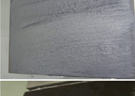


While the safety issues pertaining to abrasive blasting of live pipework have been previously mentioned, if it is required, abrasive blasting may be carried out to an SSPC-SP 6 Commercial standard, or an SSPC-SP 10 Near White Metal standard, ensuring an angular surface profile of 2–3 mils (50–75µm). Coating applications at these elevated temperatures mean that dew points are not a consideration.

To achieve the specified 8 mils (200 µm) total DFT of the coating, two-coat applications are undertaken using brushes with synthetic filaments, or no-pilling 5 mm rollers with microfibers.

Care must always be taken not to apply a heavy coat directly to the hot steel; otherwise, film bubbling can occur. The maximum total DFT of the hot-spread coating is 16 mils (400 µm). Excessive film thicknesses must be avoided as they could lead to cracking in the cured coating film. Due to the rapid cure of the hot-spread epoxy coating at high temperatures, measurement of the wet film thickness is not possible. Dry film thickness measurement on hot steel is difficult and should be carried out with care.

Observations in a side-by-side comparison of coatings applied to hot steel at 302 F (150 C) are shown in Table 6. A particular observation was made about the IMM coating tested that resulted in a very wide DFT range due to its poor ability to spread into a smooth even film (Fig. 9).

Table 6: Application of Coatings Directly to Hot Steel at 302 F (150 C)

Coating	Coating Application Remarks	Coating Appearance During Application	Coating Appearance After Application	Coating Defects	Fumes from Application
Hot-spread epoxy phenolic	Some bubbling; long wet edge time; which leaves enough time to get a smooth and even film			None / low level of brush marks	Low
IMM (1K)	Significant bubbling; balling up, setting very fast, cannot be spread properly. High DFT variance			No cohesive film / non-uniform film	Medium
Epoxy phenolic alkylated amine	Bubbling; spreads well in contact with hot substrate			Brush marks and uneven	Low
Epoxy phenolic	Significant bubbling; spreads well, but wet edge time too short; cures fast on brush			Brush marks and uneven	High

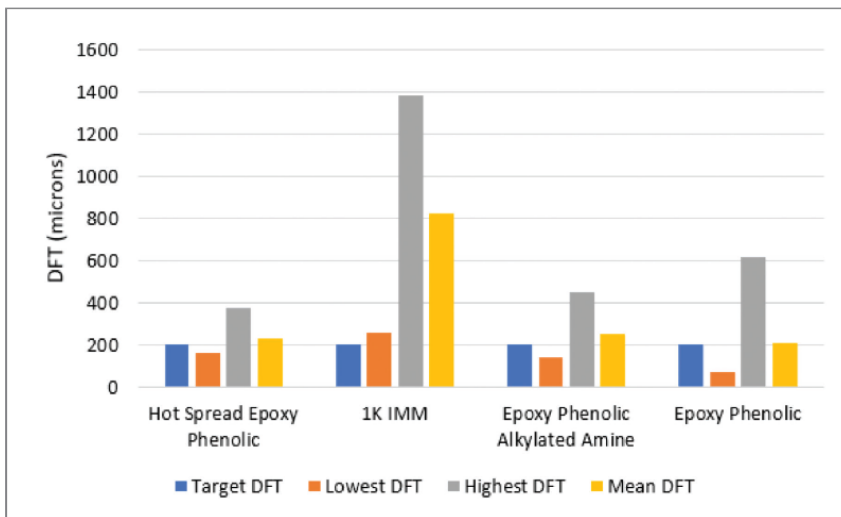


Fig. 9: The comparison shows the measured DFTs of coatings applied to hot steel at 302 F (150 C).

CASE STUDY NO. 1

Process piping at an oil and gas facility was abrasive blasted to an SSPC-SP 10/NACE No. 2 standard. Weather conditions were cloudy and windy, with intermittent rain and an outdoor temperature of 38 F (3.2 C). With scaffolding in place, coverage with tarpaulins and tenting, the worksite was well ventilated and protected against inclement weather conditions.

Because the hot-spread epoxy phenolic is viscous prior to use, it was recommended that the part A base resin and part B converter containers be stored overnight at 77 F (25 C). Despite doing so, however, the next day and prior to use, the coating components had cooled down.

All personnel wore appropriate respiratory and personal protective equipment throughout the coating work. The part A base resin was premixed with a power mixer, noting little to no settlement, and then mixed with part B converter via the same method.

Using an infrared thermometer, the surface temperature of the process pipe was found to be 290 F (143 C). To aid in temperature retention for the coating application, temporary insulation was added to the pipe. This was later removed prior to brush application of the hot-spread epoxy phenolic coating (Fig. 10).



Fig. 10: The hot-spread epoxy phenolic coating was brush-applied to hot steel pipes.

The release of solvent from the coating during its application left a slight orange-peel effect, but this was not deemed an issue. After 10 minutes of cure time, the coating hardness was checked and found to be satisfactory to carry out DFT measurements, which were found to be within specification guidelines. The applicators noted the fast dry time and how quickly insulation could be reapplied to the pipework.

CASE STUDY NO. 2

At a chemical plant, the hot-spread epoxy phenolic coating was applied on two pipes on a pipe bridge both by brush and roller, after hand-tool cleaning to SSPC-SP 2/St 2. The surface temperature during application was 257 F (125 C). During the application, the applicator observed no surface defects, including pinholes. The excellent brushing properties gave a smooth continuous film, with a low level of solvent fumes emitted, which was hard dry in less than 10 minutes with an average dry film thickness from 10 measurements of 8 mils (200 μm).

Seven months later, the pipes were inspected. The insulation was removed and when a week of rain had finally subsided, inspection could be carried out (Fig. 11). Adhesion testing was carried out by X-cut, and without tape, since the pipe was hot. Adhesion was rated 10 according to the ASTM D6677 standard.¹⁰ The inspection reported no cracks or film defects of any kind and concluded that the condition of the hot spread epoxy was virtually the same as the day it had been applied.



Fig. 11: At left is a photo taken during inspection of the hot-spread epoxy phenolic coating after seven months in service. The right exhibits the X-cut adhesion test, showing a rating of 10.

CASE STUDY NO. 3

At an oil production facility, the hot-spread epoxy phenolic was applied to a blank section of a hot oil pipeline (Fig. 12). The carbon steel was power-tool cleaned to an SSPC-SP 2/St 2 cleanliness standard and the hot-spread epoxy phenolic was applied by brush. The substrate temperature was 356 F (180 C) to 379 F (193 C), the air temperature was 77 F (25 C) and the relative humidity was 77%.

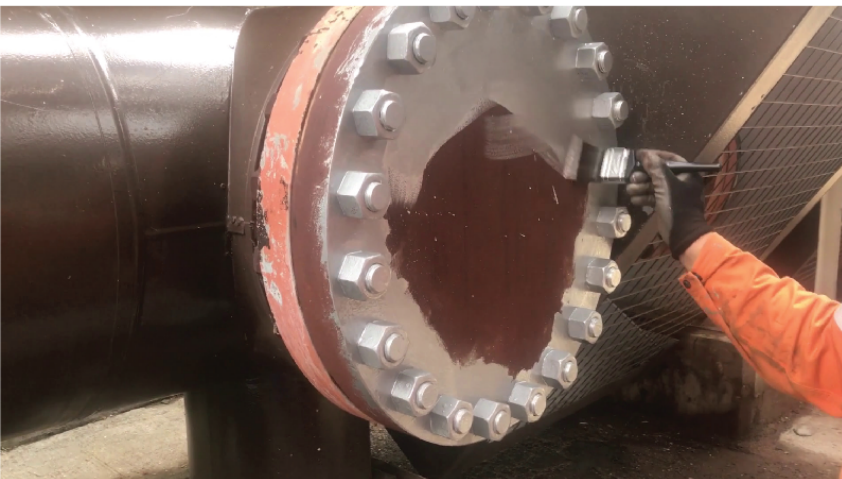


Figure 12: Brush application was carried out on the hot-oil blank section.

The applicator noted the ease with which the hot-spread epoxy phenolic could be applied to cover the blank section. The level of finish achieved was satisfactory and there was very little evidence of brush marks.

CONCLUSION: FROM CONFUSION TO FUSION

For chemical plant and refinery owners, any confusion over which coatings to use and which not to use on hot rusted steel pipes, valves and vessels, can be removed using a fusion of molecular engineering in hot-spread epoxy phenolic technology. In a nutshell, the latter provides a cost-effective CUI strategy to minimize maintenance and repair shutdowns and reduce downtime— all without sacrificing future asset performance.

In the final analysis, the contradistinction of insidious ravages from CUI costing exorbitant sums of money, to the ability to carry out planned (or even emergency) maintenance for hot and operational rusted pipes, valves and vessels saving enormous sums of money, is a welcome turnaround (pun intended) for chemical and refinery owners.

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